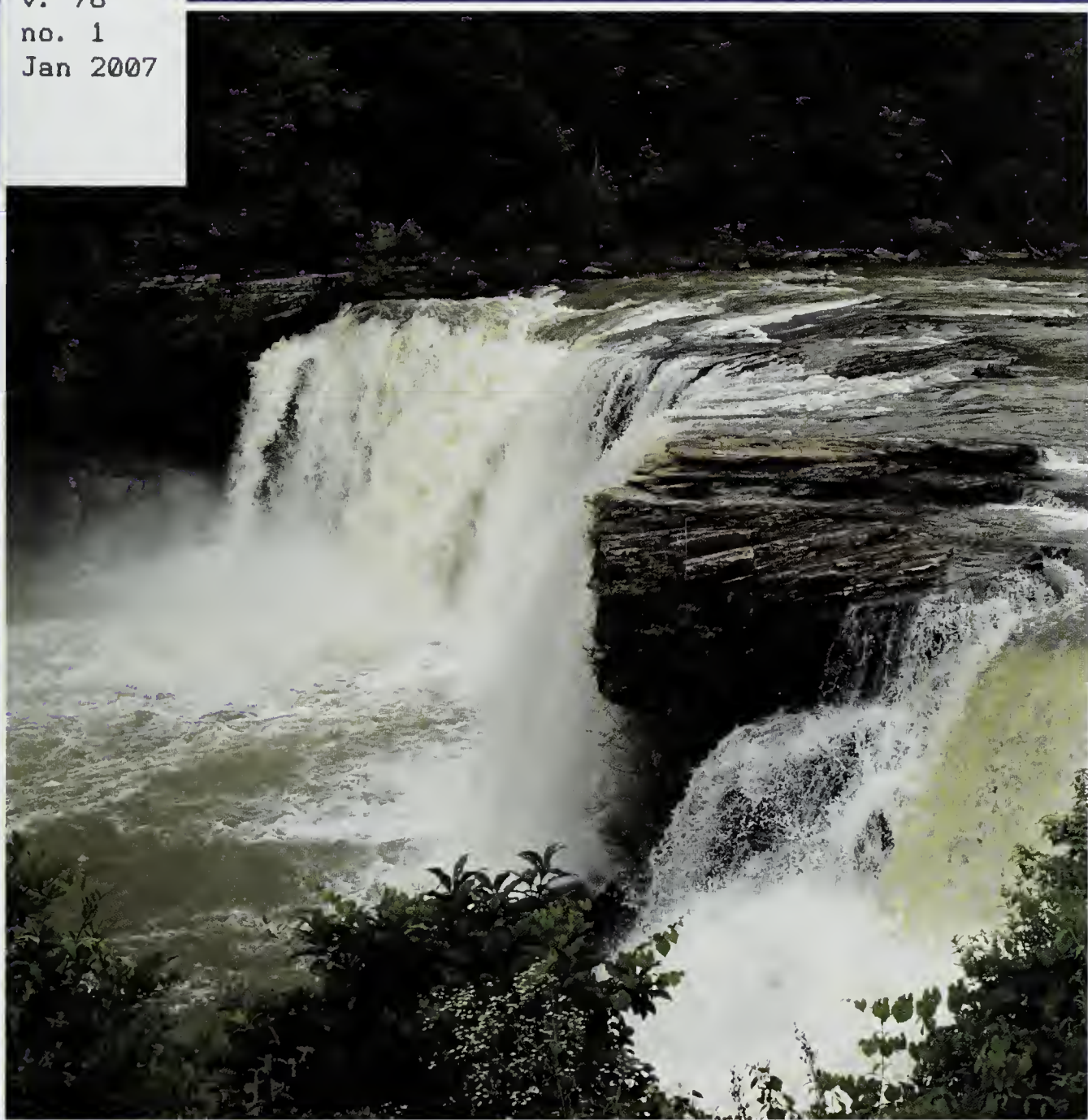


# THE JOURNAL OF THE ALABAMA ACADEMY OF SCIENCE

Q11  
.J68  
v. 78  
no. 1  
Jan 2007



VOLUME 78

JANUARY 2007

NO. 1

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**Photo courtesy of:** Dr. Frank A. Romano, III, Professor of Biology, Jacksonville State University

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**THE JOURNAL  
OF THE  
ALABAMA ACADEMY  
OF SCIENCE  
AFFILIATED WITH THE  
AMERICAN ASSOCIATION FOR THE  
ADVANCEMENT OF SCIENCE**

VOLUME 78

JANUARY 2007

NO.1

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ISSN 002-4112



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# INTERACTIONS BETWEEN THE RED HILLS SALAMANDER AND ITS POTENTIAL INVERTEBRATE PREY

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## ABSTRACT

The foraging habits of Red Hills Salamanders (*Phaeognathus hubrichti*) at their burrow entrances were observed using a video camera. The number of prey available and the number of times salamanders oriented were counted, attempted and prey items were successfully captured. Red Hills Salamanders were sit-and-wait predators that successfully captured and consumed earthworms and unidentifiable insect larvae. They oriented toward but did not capture camel crickets (*Ceuthophilus* sp.) and did not visibly react to harvestmen (*Leiobunum* sp.). Camel crickets immediately hopped away when they touched a salamander with their long antennae, and harvestmen did not visibly react to a salamander, even at distances less than 2 cm. This study is unique in documenting the foraging behavior of a salamander in the field, over a long time period, with minimal disturbance to either the salamander or its prey.

## INTRODUCTION

Salamanders are predators on a wide variety of invertebrates. Many species are sit-and-wait type predators, whereas a few actively forage (Duellman and Trueb, 1986). Sit-and-wait type predators generally consume active prey whereas widely foraging predators eat sedentary prey. Prey must disrupt one or several of these phases to avoid being eaten: detection, identification, approach, subjugation and/or consumption (Endler, 1986). Thus in any predator-prey system, there are physiological, ecological and behavioral interactions that influence the types of prey eaten by the predator and the rate of consumption of the individual prey types. Typically nocturnal, terrestrial salamanders are secretive, living under rocks, logs, leaf litter, or in burrows (Petranka, 1998). However, the natural history of the Red Hills Salamander (*Phaeognathus hubrichti*, Highton, 1961) allows for direct field observation of this salamander's foraging behaviors and the behaviors of its potential prey in response to the presence of a salamander.

The monotypic Red Hills Salamander is a large (total length to 25.5cm) fossorial plethodontid endemic to the Red Hills region of south-central Alabama (Mount, 1975).

Entirely terrestrial, it lives in burrows found in the sides of steep ravines, composed of a soft siltstone/mudstone, well shaded by a hardwood overstory (Brandon, 1965; Schwaner and Mount, 1970; Dodd, 1991). All aspects of its life history are associated with these extensively branched and interconnecting burrows which the salamanders have not been observed to dig (Brandon, 1965; Jordan, 1975). Each burrow entrance is oval in shape (approximately 20% higher than wide) with a smooth rounded rim and smooth packed floors and walls (Valentine, 1963; Schwaner and Mount, 1970). Salamanders are found at burrow entrances, on average 12.3 hrs, mainly during darkness, although there is limited diurnal activity, and they rarely leave their burrows (Bakkegard, 2002). This burrow centric behavior allows for continuous, direct observation in the field, using a video camera, of the foraging habits at a burrow entrance and the behavioral interactions between the salamander (a predator of the local invertebrate community) and its prey.

This study is unique among studies of salamanders in that it documents foraging behavior in the field over a long period of time with minimal disturbance to the animals being observed. I studied the foraging behavior of the Red Hills Salamander by documenting the total prey availability, the prey types toward which salamanders oriented and the prey types that salamanders successfully captured and consumed at or near their burrow entrances. I also examined the behavioral interactions between the predatory salamander and two of its potential prey, camel crickets and harvestmen. I focused on these two potential prey because they were abundant and had contrasting behaviors. Foraging by this salamander has only been observed in the field twice (Jordan, 1975), although there are some dietary data based on analyses of stomach contents and fecal pellets (Brandon, 1965; Gunzburger, 1999) which I consolidated here to make this the most complete record of foraging behavior in this salamander to date.

## **MATERIALS AND METHODS**

A population of Red Hills Salamanders was studied and located at Haines Island Park, a United States Army Corps of Engineering property in Monroe County, Alabama, USA from July 1998 to December 1999. Videotaping details are described in Bakkegard (2002), and the data for this study are from the same video tapes used to quantify activity patterns in that study. To summarize: A Sony™ 8 mm TR-940 camcorder was used, mounted on a tripod and equipped with infrared illumination to record all events at and around a burrow entrance occupied by a Red Hills Salamander. Typically, videotaped burrows had a salamander present, were located so that the camera and tripod could be set up, and had not been previously videotaped. However, about 20% of the time, salamanders were not present at start time. Therefore, a burrow that was known to have been occupied based on a previous survey was chosen. Once the camera was positioned, the site was departed from, returning every 4 h to change the tape. Thirty seven different burrows were videotaped in 40 sessions. One burrow was videotaped three times, but only two sessions had salamander/potential prey interactions. These two sessions were temporally separated by eight months. Another burrow was videotaped twice, with a 1.5 month separation between sessions. Thus,

was assumed that each videotaped burrow represents a different salamander (except for the exceptions noted above) because I never saw more than one salamander in an entrance and recapture data from this site (Carroll et al., 2000) suggests that burrows are usually occupied by a single individual. Videotaping occurred for an average of 15.03 h per session (range 7.98–19.14 h) for a total of 545 h (320 h sunset to sunrise (night time) and 225 h sunrise to sunset (daytime) of which 303 h had a salamander visible on tape (250 h night time, 53 h daytime). Daytime and night time hours were distributed throughout all months, except April 1999 when no videotaping occurred.

### **Salamander responses to prey:**

Three categories were used to define salamander behavior: orientation ( $N_o$ ), attempt ( $N_A$ ) and success ( $N_s$ ). Orientation, a rapid movement of a salamander's head or body in the direction of a stimulus on or off camera, was used as a measure of salamander interest in an item. I only analyzed instances in which salamanders oriented towards potential prey visible on camera. An attempt was when a salamander snapped, lunged or extended its tongue toward a potential prey item. A success occurred when the salamander captured and consumed a prey item.

The invertebrates (potential prey) seen on the videotapes were counted and identified. For unidentifiable items, three categories were created based on the general form or type of locomotion: flying, crawling (with legs) and unidentifiable (wiggling in the soil). Potential prey seen at the same time as a salamander were also counted at an entrance (a subset of the total number of potential prey). Because the distributions of the two data sets did not differ, I only report the latter here. On two occasions, salamanders oriented multiple times toward the same trapdoor spider (*Myrmekiaphila* sp.). All such orientations were counted as one event. Moths and other flying insects were counted only if they flew into the side of the slope or tangentially along it near enough that a salamander could have potentially preyed upon it. Prey availability and feeding rate were calculated by dividing the number of prey or successes by the number of hour's salamanders were visible at entrances. Total success rate based on the total number of items salamanders captured was divided by the total number of attempts.

To determine if there was a relationship between salamander and potential prey temporal activity patterns, I calculated a Spearman correlation coefficient (data non-normal; Zar 1999) between measures of salamander and insect activity computed for each one-hour period in a day. Salamander activity was taken from Bakkegard (2002) and was computed as the number of hours that salamanders were present at entrances divided by the number of hours the camera was operational during each one hour period. Insect activity was determined similarly using the number of prey items (excluding harvestmen) observed during a particular one-hour period of the day as the numerator. Statistical analyses were conducted with SAS version 8.01 (SAS Institute, Inc., Cary, NC, USA) and  $P$  values less than 0.05 were considered significant.

Ideally, any statistical analysis of these data would use burrows (and thus salamanders) as independent replicating units. However, for this observational study, I



used potential prey items as independent observations because of substantial differences in the types of prey appearing at each burrow, in combinations with low prey counts. For the two burrows that were videotaped twice, there were no repeated measures on salamander/opilionid/orthopteran interactions. For responses of salamanders to prey, the structure of the data (high variability in the types of potential prey coupled with low prey counts) dictated a descriptive approach. However, based on observation, there appeared to be little variability in response among salamanders to potential prey items. Only one salamander (not the focal animal but one from a nearby burrow) was observed leaving burrow (twice).

### **Prey responses to salamanders:**

The interaction between Red Hills Salamanders and orthopterans (exclusively camel crickets, *Ceuthophilus* sp.) and opilionids (harvestmen, *Leiobunum* sp.) proved noteworthy as these arthropods were the two most abundant potential prey, active throughout the study, and easy to observe and identify on the videotape. I characterized camel cricket behavior into one of three classes: the salamander orients toward the cricket but the cricket does not touch the salamander with its antennae; the salamander orients and the cricket touches the salamander with its antennae; and the salamander does not orient but the cricket touches the salamander with its antennae. Behavior of harvestmen was not easily quantifiable, but is best described as searching or locomotion from one point to another. I noted the behavior of harvestmen that walked near (within approx. 2 cm) or directly over a salamander burrow with a salamander present, and compared that to the behavior of harvestmen that were seen on camera but were not near (> approx. 2 cm) to a salamander.

## **RESULTS**

### **Salamander responses to prey:**

A total of 250 potential prey items were observed; 190 of these were present simultaneously with a salamander at an entrance. The most abundant potential prey items were Orthopterans (camel crickets, *Ceuthophilus* sp.), Opiliones (harvestmen, *Leiobunum* sp.), crawling arthropods, and Hymenoptera (ants and 1 wasp; Table 1). More prey was present during nighttime than daylight hours (Fig. 1). There was a positive and significant correlation between salamander activity and insect activity ( $r_s = 0.57$ ,  $P = 0.004$ ,  $N = 24$ ). The rate of prey availability (when salamanders present) was 15.0 items/day including Opilionids, and 11.6 items/day, excluding Opilionids.

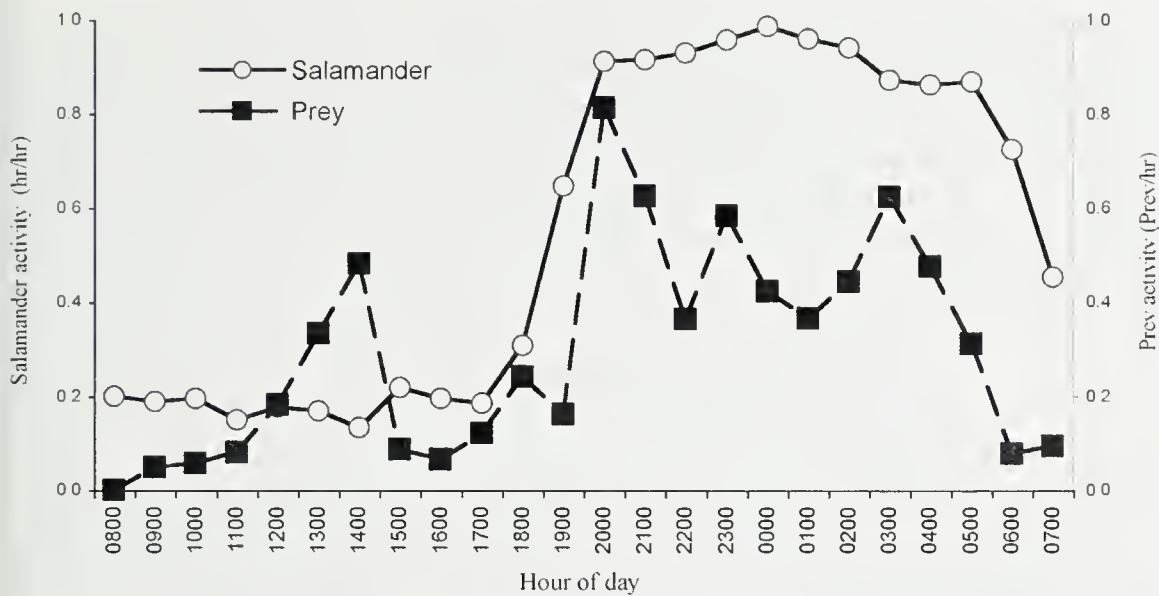
Table 1. Prey items consumed by *Phaeognathus hubrichti*, Monroe County, Alabama.

Item	E	N	No	NA	Ns	Nj	NG	NB
Arachnida	5	5	2	2	0	—	3	1**
Blatteria	—	—	—	—	—	1	1	—
Coleoptera	3	3	2	1	0	—	6	7
Diplopoda	—	—	—	—	—	—	3	6
Diptera	—	—	—	—	—	—	—	1
Gastropoda	—	—	—	—	—	—	10	7
Hemiptera	—	—	—	—	—	—	1	—
Hymenoptera	8	18	5	0	0	—	9	6
Lepidoptera	5	8	3	2	0	—	—	—
Oligochaeta	1	7	3	2	2	—	1	—
Opiliones	13	44	3	0	0	—	—	—
Orthoptera	17	52	24	3	0	1*	—	—
Insect larvae	9	14	14	8	6	—	1	—
Crawling	15	24	8	4	0	—	—	—
Flying	5	6	2	1	0	—	—	—
Unidentifiable	8	9	9	7	2	—	10	9

\*Only leg of the Tettigoniidae was successfully consumed, remainder of insect escaped.

\*\*E is the number of salamanders exposed to each potential prey item. N is the total number of potential prey items available when a salamander was present at an entrance. N<sub>O</sub>, N<sub>A</sub>, and N<sub>S</sub> are the number of prey items salamanders oriented toward, attempted to eat, and successfully captured. N<sub>J</sub> is the number of prey items captured by salamanders at a burrow entrance as observed by Jordan (1975). N<sub>G</sub> and N<sub>B</sub> are the number of prey items found in the guts and fecal samples by Gunzburger (1999) and Brandon (1965) respectively.

Twenty five salamanders oriented toward 75 potential prey. On an additional 97 occasions, salamanders oriented toward objects outside the camera’s field of view. Salamanders oriented toward all types of potential prey and attempted to capture all prey types except for Opilionids and Hymenoptera (Table 1). The orientations observed for insect larvae and the unidentifiable category may be artificially high because many of these prey were noted only because salamanders oriented toward them. Earthworms (Oligochaeta) were visible only one night when there was heavy rain and also may be overrepresented. Salamanders do not orient equally towards Opilionids and Orthopterans. Seven salamanders were exposed to both Opilionids (1–7 per salamander, 21 total Opilionids) and Orthopterans (2–5 per salamander, 25 total Orthopterans). These seven salamanders oriented toward zero Opilionids and 13 Orthopterans. Table 1 show that selectivity is largely restricted to the avoidance of Opilionids and preference for insect larvae, and orientation towards other prey in rough proportion to their occurrences at burrow entrances.



**Figure 1. Activity pattern of *Phaeognathus hubrichti* (from Bakkegard, 2002) and prey items (excluding harvestmen) by hour of day.**

Salamander activity represents the number of hours salamanders were present at entrances divided by the number of hours the camera was operational during that period. Prey activity is the number of prey items (excluding harvestmen) divided by the number of hours the camera was operational during that period.

Thirty feeding attempts resulted in 10 successful prey captures (33%) by seven salamanders. There were two additional attempts (a crawling item and an unidentifiable item) in which I was unable to determine if the salamander successfully captured it. No salamander left the field of view of the camera during videotaping so no prey items were captured off camera. Salamanders were successful in capturing and consuming oligochaetes, insect larvae and unidentifiable items (Table 1). Salamanders fed at a rate of 0.79 prey items/day.

### **Prey responses to salamanders:**

Of 14 camel crickets whose antennae touched a salamander, 13 hopped away (immediately to 9 s,  $\bar{X} = 1.7$  s,  $SD = 2.21$ ). One cricket continued to walk normally after touching the salamander with one antenna. Of the 13 occasions where the salamander oriented but the cricket did not touch the salamander, three of those hopped away or left the camera's field of view in apparent response to the salamander. Of the remaining 10, the cricket moved normally through the area (1 s to 7.42 min,  $\bar{X} = 2.45$  min,  $SD = 3.36$  min) and did not appear to notice the salamander (7 of 10) or only antennae (3 of 10) were visible on the videotape. Of the three predation attempts salamanders made on crickets, the cricket escaped by hopping away. None flew to escape because *Ceuthophilus* are wingless (Scudder, 1894).



Ten harvestmen walked next to a burrow with a salamander present at an entrance, four walked over a burrow with a salamander present and may have touched the salamander, and two clearly touched a salamander with their walking legs. Of these 16 close encounters between a salamander and a harvestman, only one salamander oriented toward a harvestman. In all instances, harvestmen did not appear to move more quickly, change posture or respond in any fashion to the presence of salamanders. No salamander attempted to capture a harvestman.

## DISCUSSION

### Salamander response to prey:

Red Hills salamanders were active when prey activity was high, although activity of each may be independent of the other as the same factors that favor salamander activity may also favor prey activity. With the exception of harvestmen, salamanders oriented toward invertebrates moving near their burrow entrances in the same proportion that prey items were available. Salamanders oriented towards beetles, camel crickets and earthworms, prey that move actively through the environment. Salamanders in general ignore stationary prey objects, although the complex relationship between prey size, movement pattern and olfactory cues determines if a salamander will attack a prey item (Roth, 1987). Salamanders also oriented toward insects that flew near their burrows. These observations suggest that Red Hills Salamanders have good visual acuity or is at least responsive to small moving objects, even in darkness, a result similar to that reported in other salamander species (Roth, 1987).

At burrow entrances, Red Hills Salamanders appear to be exclusively sit-and-wait predators as they did not leave their burrows to search the forest floor for prey. The usual position of a Red Hills Salamander at its burrow entrance was with the head and front legs outside the entrance and the body and tail inside the burrow (Bakkegard, 2002). To capture prey, a salamander slowly advanced and, if required, anchored its hind legs in the burrow entrance, then attacked. Salamanders also would snap at prey without an advance, especially if the prey was moving rapidly. Only once did a salamander leave its burrow to pursue a prey item, an insect larvae crawling across the surface near its burrow. When the salamander failed to capture the larvae, it quickly returned to its burrow, entering head first but turning around to face outward again in approx 3 sec. Red Hills Salamanders used tongue extensions and jaw snaps singly or in concert to capture prey. This method of prey capture conforms with the morphological observations of Lombard and Wake (1977). When salamanders were successful, they retracted into the burrow immediately after grasping the prey, reappearing at the burrow entrance after consuming the prey as Jordan (1975) also observed. The success rate of Red Hills Salamanders (33%) was comparable to that of *Salamandra salamandra*, which captured 39% of the crickets presented to it in a laboratory setting (Luthardt-Laimer, 1983), but less than the success rates of other plethodontids, including *Plethodon*, *Eurycea*, and *Batrachoseps* (> 50%; Roth, 1987).

At the burrow entrance, Red Hills Salamanders captured slow and soft-bodied



prey. These salamanders are capable of catching fast and hard bodied prey (Brandon, 1965; Jordan, 1975; Gunzburger, 1999) and in captivity, consume domestic crickets *Acheta domestica* (Bakkegard, pers obs.). However, the majority of the prey items (ants, snails, millipedes, insect larvae and earthworms) listed in dietary studies are relatively slow. In contrast, other sit-and-wait predators, such as lizards and tropical litter frogs, capture a low number of large mobile prey (Huey and Pianka, 1981; Toft, 1981). I would classify spiders (except for the trapdoor spiders present at the site), harvestmen, camel crickets, moths and beetles as mobile prey that move actively through the environment. However, Red Hills Salamanders were ineffective at capturing these prey items at the surface. Thus the diet of Red Hills Salamanders is not consistent with predictions based on foraging theory. This inability to capture faster prey may be due to their limited tongue projection capability (Lombard and Wake, 1977), their lack of pursuit of prey items further away from the burrow entrance than the body length of the salamander, or because the prey itself is difficult to capture, as appears to be the case with camel crickets. My observations, coupled with the dietary studies (Brandon, 1965; Jordan, 1975; Gunzburger, 1999), suggest that when salamanders capture mobile prey, it may be inside the burrow.

Red Hills salamanders displayed selective foraging in that the frequency of orientation toward harvestmen was conspicuously less than the frequency with which they were available in the environment. Salamanders do not appear to recognize (detection and/or identification phase of a predation event) harvestmen as prey items. This was surprising because when a harvestman walks, its body bobs up and down providing a strong visual stimulus. Harvestmen secrete a variety of volatile defensive compounds (disrupting subjugation) but do so only when disturbed (Edgar, 1971; Eisner et al., 1978; Blum, 1981). Salamanders will reject aversive tasting stimuli (Bowerman and Kinnamon 1994; Takeuchi et al. 1994). Although studies of learning in amphibians are scarce (Suboski, 1992; Muzio, 1999), *Bufo terrestris* avoided eating bee mimics after earlier being stung when feeding on true bees (Brower et al., 1960; Brower and Brower, 1962). Thus, Red Hills salamanders may learn that harvestmen are unpalatable. Because they live approximately 11 yr (Parham et al., 1996), study of the long-term retention of an avoidance behavior in salamanders may prove interesting.

### **Prey response to salamanders:**

When moving normally through the environment, camel crickets constantly touched the area ahead of them with their long antennae. They appeared to recognize that Red Hills Salamanders were a potential threat as evidenced by immediately hopping away upon contacting a salamander with their antennae, disrupting the approach phase of a predation event. Orthopteran antennae are sensory and tactile appendages containing a variety of sensilla that function as mechano, chemo, and olfactory receptors (Zacharuk, 1985; Bland, 1989). When the antenna of the cockroach *Periplaneta americana* was touched by a predator (spider, toad, mantis, or mouse), the cockroach turned away and displayed escape behavior, even in the absence of simultaneous wind or visual predatory cues (Comer et al., 1994). They also observed that in some trials, the roach would touch

the predator with its antennae first and then run. There was no obvious movement by the predator and they speculated that tactile, proprioceptive and chemical cues were probably being processed. Similarly, camel crickets (with a sensory system similar to cockroaches) reacted to Red Hills Salamanders with no discernable movement by a salamander. The stimulus was the cricket's antennae contacting a salamander's head or body. Perhaps these camel crickets have evolved an innate reaction to contact with Red Hills Salamanders or to amphibians in general. Alternatively, the camel crickets at this site may have escaped previous predation attempts and associate a salamander cue with an imminent attack.

In contrast, harvestmen did not noticeably change their behavior when in close vicinity to a salamander. Harvestmen defensive mechanisms include playing dead, losing a leg, secreting a foul smelling/tasting substance from a pair of glands (an option of last resort), or running away (Edgar, 1971; Eisner et al., 1978). None of these behaviors were observed. This suggests that they did not perceive Red Hills Salamanders as a threat or that the harvestmen at this site display defensive behaviors only when attacked.

Maiorana (1978) evaluated several indirect methods used to determine diet selectivity in salamanders because "One cannot watch salamanders select food directly in the field". However, this observational study, conducted in the field, exposes the complexity of predator-prey interactions. Camel crickets are difficult prey items for Red Hills Salamanders to capture at the surface, but this may change when a cricket enters a burrow (I observed one crawling into a salamander burrow during daylight). The camel cricket's escape method, hopping away, is probably ineffective in a confined space. Interactions between Red Hills Salamanders and harvestmen could be described as a mutual ignoring of each other. This suggests either learning by individual salamanders and/or the inability of harvestmen to recognize salamanders as a potential predator or the salamander to recognize harvestmen as a potential prey. Although valuable, dietary studies of gut contents, even when coupled with analyses of available prey and other variables (often morphological), cannot capture the nuances of predator-prey interactions.

## ACKNOWLEDGEMENTS

I would like to thank C. Guyer for his invaluable guidance and support in all aspects of this study. E. D. Brodie, Jr., the USU herpetology group and several anonymous reviewers contributed useful comments on the manuscript. G. Mullen assisted in the identification of the Opilionids. S. Durham provided statistical assistance. The U.S. Army Corps of Engineers, Mobile District provided a campsite at Isaac Creek Campground. Funding was provided by the Nature Conservancy. This study was conducted under a permit provided by K. Guyse, Department of Conservation and Natural Resources, State of Alabama (letter of permission 1998, 1999) and Auburn University IACUC protocol 12-R-0844.

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## EFFECT OF VARIOUS PHOTSENSITIVE DYES ON THE GROWTH OF TETRAHYMENA IN VITRO

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### ABSTRACT

Photodynamic action associated with light activation of photosensitive dyes has been used to control various human health disorders and agricultural pests. These dyes are considered effective alternatives compared to current treatments with known negative impacts on the environment. In the present study the efficacy of the following dyes for potential pest management was examined: methylene blue, eosin yellow, acridine orange, rose bengal, and phloxine B. Cultures of *Tetrahymena pyriformis*, a commonly used protozoan model for ecotoxicological evaluation, were exposed to the photodynamic dyes at various concentrations, at 25°C, in light ( $66 \mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ ), and in the dark ( $0 \mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ ) for 24 h. In the dark, cell growth was inhibited by all the dyes. Only a 5% to 10% variation in growth inhibition was observed at dye concentrations of 100, 1000, and 10000 ppb. In the presence of light, all the photodynamic dyes tested exhibited a linear log dose response curve of photodynamic action. The deleterious effects of the dyes were detected at concentrations as low as 100 ppb.

### INTRODUCTION

“*Photodynamischem Wirkung*” (‘photodynamic action’) was coined in 1904 by von Tappeiner and Jodlbauer as the deteriorating effects of chemicals interacting with visible light in various biological systems (Blum, 1941). A variety of compounds, including synthetic dyes, drugs, antibiotics, and plant secondary compounds, have been shown to exhibit this photodynamic effect (Santamaria and Prino, 1972). Lipid peroxidation, membrane lysis, DNA base modification and strand breakage, mutagenesis, protein inactivation, and inhibition of metabolic pathways are the types of cellular photodamage that occur (Wallis and Melnick, 1965; Foote, 1976). These wide ranges of targets damaged by photodynamic action make it less likely that any organism will be able to mutate cellular components and develop resistance (Jori et al., 2006). A renewed interest in photodynamic action, accompanied by the development of new photosensitive dyes and recent advancements in light delivery, has advanced this technique for the inactivation and destruction of various

biological systems (Stapleton and Rhodes, 2003). Currently, photodynamic therapy (PDT) is one of the newest treatments of various microbial, viral, and inflammatory disorders (Badylak et al., 1983; Ali and Olivio, 2003). PDT proved to be an effective alternative cancer treatment and is also used in experimental studies of dermatology, ophthalmology, and gastroenterology (Henderson, 1992; Meisel and Kocher, 2005).

In an aim to control agricultural pests, such as insects, protozoan, bacteria, and fungi, ongoing research of alternative methods and treatments with a variety of chemical compounds has been explored (Heitz, 1997). These alternatives are replacements for current chemical structures and strategies that have been rendered ineffective by resistance and negative environmental impacts (Heitz, 1997). Effects of photosensitive dyes on insects have been studied since the early seventies. These earlier investigations have demonstrated the usefulness of phototoxic dyes as an alternative to other chemical pesticides. Research demonstrated the photodynamic effects of the following dyes on the order Diptera: rhodamine, rose bengal, erythrosin B, eosin blue, phenosafranin, methylene blue chloride, and uranine (Yoho et al., 1971). Dye mixtures have been formulated in baits that are attractive to the target species (fruit fly); the dye is activated to its phototoxic state only after ingestion and exposure to light through the transparent gut of the insect (Chase, 1996).

This study was aimed at evaluating the photodynamic effects of selected photosensitive dyes on the protozoan *T. pyriformis*. *Tetrahymena pyriformis* serve as an excellent ciliated protozoa model for the toxicological evaluations of carcinogens, insecticides, dyes, and pharmaceutical drugs due to the ease of culturing, which allows *in vitro* screening of multiple chemicals without expensive animal facilities (Sauvant et al., 1999). The photodynamic dyes examined are acridine (acridine orange), phenothiazinium (methylene blue), and the xanthenes (phloxine B, rose bengal, and eosin yellow).

## MATERIALS AND METHODS

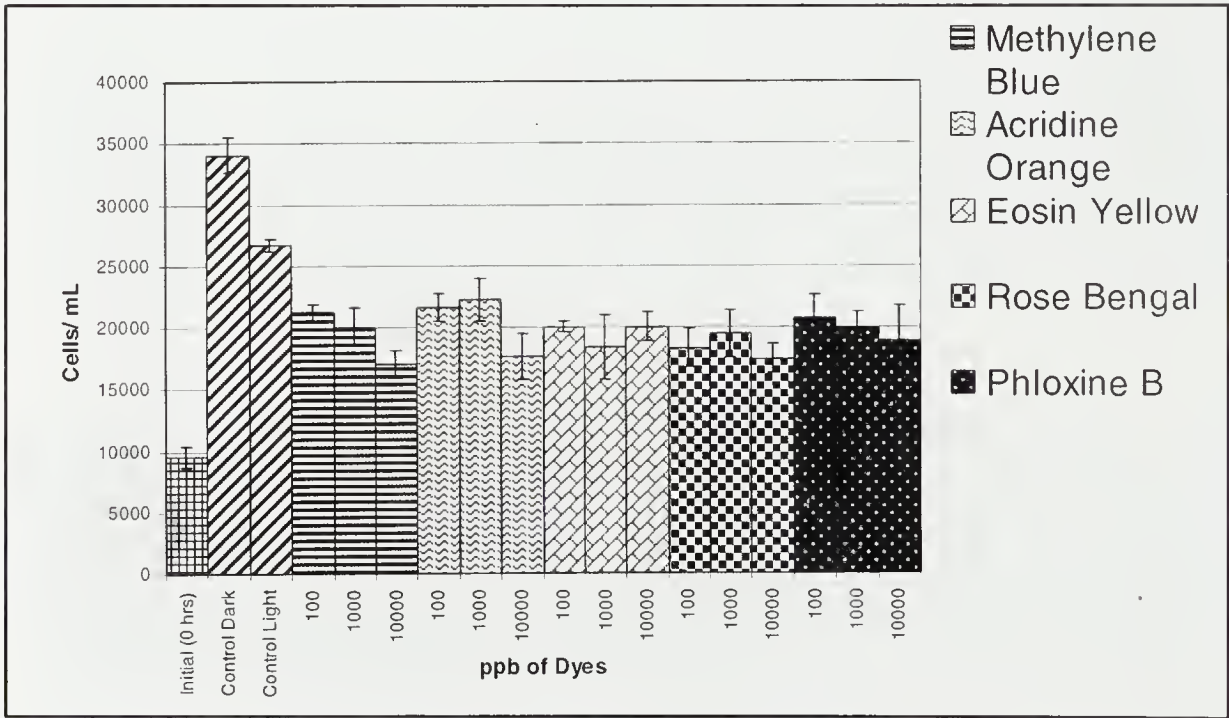
*Tetrahymena pyriformis* was obtained from Carolina Biological Supply Company and were maintained in standard media comprised of 5.0 g proteose peptone, 5.0 g Tryptone, and 0.2 g potassium phosphate in 1 L of spring water and adjusted to pH 7.2. All media were autoclaved at 15 psi, 121°C for 15 min. For test purposes, stock cultures were maintained in an environmental growth chamber (Convion Inc. CMP4030) at 25°C, 50 % humidity in the dark. Cells were cultured in 100 mL of standard medium in 250 mL Erlenmeyer flasks until cell concentrations were between 25,000-35,000 cells/mL.

The 24-h test protocol included two independent tests (light and dark) carried out in triplicate at each dye concentration. The effect of the dyes on population density during 24 h of growth was examined. Culture tubes (23 X 150 mm) containing 8 mL of fresh culture media and 8 mL of *T. pyriformis* cell suspension were exposed to concentrations of 100, 1000, and 10000 ppb of the following compounds: eosin yellow, methylene blue, acridine orange, rose bengal, and phloxine B (all obtained from Sigma Chemical Supply Company). At time zero, the dyes at 100, 1000, and 10000 ppb were added to the medium

and the tubes were swirled to evenly disperse the toxicant. All tubes were placed in the dark for 1 h in the incubator to allow absorption of the dye. Half the tubes were left in the dark ( $0 \mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ ), and half were removed and incubated in the light ( $66 \mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ ) for the remaining 23 h. Illumination of cells was carried out by using cool white fluorescent lights with a maximum spectral output around 540 nm. Light intensity ( $66 \mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ ) was used, as measured with a light meter (LI-COR Inc. LI-250). Culture tubes were inclined at a  $75^\circ$  angle to increase surface area. Cell density was evaluated turbidimetrically (LaMotte model 2020). Dark and light control mean cell densities  $\pm 1$  SD of *T. pyriformis* cultures were compared using Student's t-test after 24 h in light ( $66 \mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ ) or in the dark ( $0 \mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ ). The least-square method was used to calculate a regression line for each dye. The light and dark data were analyzed using SYSTAT® 11 and an ANOVA and Tukey's HSD were used for comparisons.

### RESULTS

In the dark, the effect of all the dyes was a significant ( $p < 0.001$ ) reduction on cell density compared to the dark control. The inhibitory effects of the dyes in the dark were similar and were not dose dependent (Fig. 1).



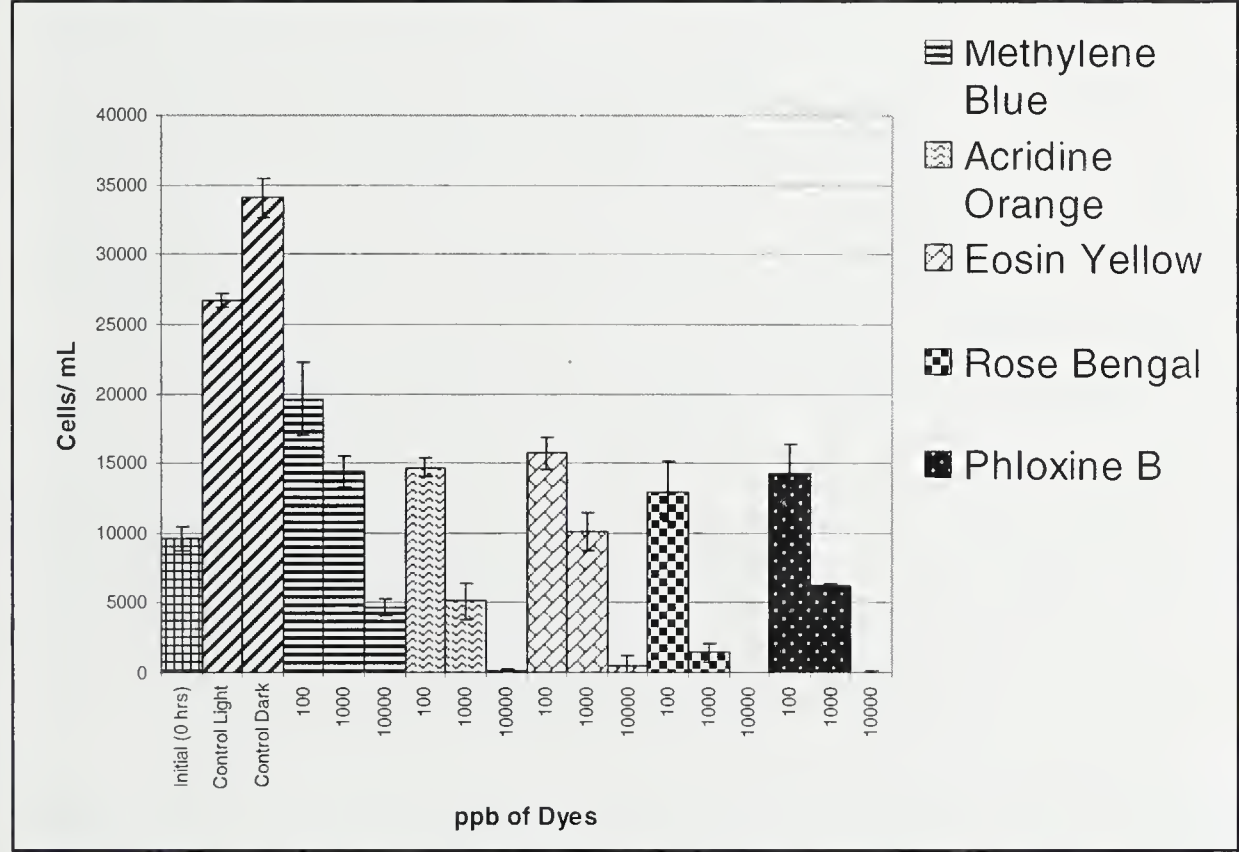
**Figure 1. Effects of methylene blue, acridine orange, eosin yellow, rose bengal, and phloxine B on the mean cell number of *Tetrahymena* after 24 hours in the dark ( $0 \mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ ). Error bars denote  $\pm 1$  standard deviation.**

Methylene blue, acridine orange, and phloxine B appeared to have a dose dependent action in the dark; however, regression analyses of the dyes revealed that there were no significant dose dependent responses. The reduced growth associated with dye concentrations of 100,



1000, and 10000 ppb differed only by 5% to 10%.

The effect of light alone on *T. pyriformis* is illustrated in Figs.1 and 2. Control cells grown in the light are significantly ( $p < 0.001$ ) inhibited when compared to control cells incubated in the dark. In the presence of light, all photodynamic dyes tested exhibited a linear log dose response curve of photodynamic action (Fig. 2). Methylene blue was the least effective dye at reducing cell density. At 100 and 1000 ppb, methylene blue treated cell cultures grew to 73% and 54% of light control cell growth respectively in the 24 h period. Acridine orange at 1000 and 10000 ppb inhibited *T. pyriformis* cell growth by 81% and 99% respectively compared to light control. The xanthene dyes (eosin yellow, rose bengal, and phloxine B) reduced cell density the most. Eosin yellow at 100, 1000, and 10000 ppb decreased cell growth by 41%, 62%, and 98% respectively compared to light control. Rose bengal completely inhibited cell growth at 10000 ppb. Phloxine B completely inhibited cell growth at 10000 ppb.



**Figure 2. Effects of methylene blue, acridine orange, eosin yellow, rose bengal, and phloxine B on mean cell number of *Tetrahymena* after the 24 hour light exposure ( $66 \mu\text{Em}^{-2}\text{s}^{-1}$ ). Error bars denote  $\pm 1$  standard deviation.**

At 100 and 1000 ppb, rose bengal inhibited cell growth by 52% and 95% respectively compared to light control. Phloxine B at the three concentrations inhibited *T. pyriformis* cell growth by 47%, 77%, and 99% respectively compared to light control.

## DISCUSSION

The relative effectiveness and environmental friendliness of photosensitive dyes have promoted investigations of their use in various fields of science (Henderson, 1992; Heitz, 1997; McBride, 2002; Jori et al., 2006). The photodynamic action of these dyes in the management of human disorders and pests is dependent on the method of dye and light delivery (Pooler and Valenzano, 1982; Stapelton and Rhodes, 2003; Meisel and Kocher, 2005). Photosensitive dyes are toxic to organisms that do not have strong pigmentation or greater body mass; therefore, it is unlikely that non-target organisms with the above mentioned anatomical traits would be harmed (Heitz, 1997; Thomas and Meats, 1999; McNeill and Goldson, 2001). High tolerance to the photosensitive dye phloxine B was reported in the 2<sup>nd</sup> instar larvae stages of two leafroller species, *Epiphyas postvittana* (Walker) and *Planotortrix excessana* (Walker), that exhibited greater body mass and darker pigmentations relative to the 1<sup>st</sup> instar larvae stages of both species (McNeill and Goldson, 2001). The potential risk effects of photodynamic dyes, particularly the xanthenes, on reported target and non-target organisms are dependent upon factors including: illumination, dye concentration and availability, and the organism's physical and structural properties (Heitz, 1997; Martin et al., 1998; Mischke et al., 1998; Walthall and Stark, 1998). These dyes use light energy to facilitate a variety of reactions between oxygen and susceptible molecules, which may lead to cellular inactivation of these smaller bodied organisms including the test organism used in this study, *T. pyriformis*.

In the dark, the effect of the dyes was a significant ( $p < 0.001$ ) reduction on cell growth. The mean cell densities of the treated cells were reduced by 40-50% compared to dark control. In the dark, the deleterious effect of all dyes at 100, 1000, and 10000 ppb differed only by 5% to 10% and have significant overlap (Fig 1). This non-specific deleterious effect, which is not dose dependent, is not due to photodynamic action. More likely, since cultures remain in the dark, the addition of the dyes interferes with some nutrient or other essential component of the culture media, thus slowing cell growth. Other studies also report similar inhibitions by the dye alone; however, in most cases the effect was considered non-specific or not significant compared to the increased action exhibited in the light (Lukšien et al., 2005; Dutta et al., 2005).

The effect of light alone on *T. pyriformis* is illustrated in Figs. 1 and 2. Control cells grown in the light are significantly ( $p < 0.001$ ) inhibited when compared to control cells incubated in the dark. *Tetrahymena pyriformis* is negatively phototactic, and growth rate is naturally inhibited by light. Although light alone can reduce the growth of *T. pyriformis*, the combination of dye and light further reduced growth, likely due to a photodynamic effect of the dye. In the presence of light, all photosensitive dyes tested exhibited a linear log dose response curve of photodynamic action (Fig. 2).

Methylene blue is a producer of superoxide radicals in the presence of light (Trindale et al., 2000). Furthermore, methylene blue is well known for its strong photodynamic activity on nucleic acids and their components *in vitro*. The dye causes growth inhibition of *T. pyriformis* in the light and dark. However, in the light at 10000 ppb, the dye was not as effective as the other dyes tested (Fig. 2).

In light, acridine orange is very effective in suppressing the growth of the cells at all three concentrations. However, the use of acridine orange may be impractical since this dye is possibly mutagenic and/ or carcinogenic to humans. The fact that acridine binds more specifically to DNA and has photodynamic properties may explain its suppression of *T. pyriformis* cell growth.

There are several classes of dyes that exhibit photodynamic action, but the most effective are the halogenated xanthenes (Heitz, 1997). The current investigation examined the photodynamic effect of the xanthene dyes (eosin yellow, rose bengal, and phloxine B) and found that these dyes were more effective in comparison to the other dyes tested. Eosin yellow was the least effective of the xanthene dyes, yet at 10000 ppb it inhibited cell growth by 98% compared to light control. Rose bengal exhibited a strong photodynamic action in light, even at 100 ppb. At 10000 ppb it completely inhibited *T. pyriformis* growth. Rose bengal is among the most widely used of all photodynamic sensitizers for single oxygen production (Paczkowska et al., 1985). The highly reactive singlet oxygen leads to loss of membrane integrity through lipid peroxidation and inactivation of essential enzymes (Castano et al, 2004). *Tetrahymena pyriformis* cell density was most likely inhibited by the oxidation of significant biomolecules (Walthall and Stark, 1999).

Phloxine B also exhibited an effective photodynamic action in the growth suppression of *T. pyriformis* at the three concentrations tested in this study. At 100, 1000, and 10000 ppb cell growth was inhibited by 47%, 77%, and 99% respectively compared to light control cell growth. The United States Food and Drug Administration (USDA) has approved phloxine B (D&C Red 27 and 28) for human consumption at concentrations of  $1.25 \text{ mg} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$ . Phloxine B is a water-soluble xanthene dye, and has a chemical half-life of 0.5 h in water exposed to sunlight (Bergsten, 1997). The safety of phloxine B to humans and other vertebrates makes it especially useful where non-target organisms may also be exposed to the dye. In the search for an effective and environmentally safe non-toxic biological control agent, the photodynamic effect and biodegradability of phloxine B are essential and practical considerations for an effective program in protozoan control.

## ACKNOWLEDGEMENTS

The authors are grateful to Dr. Tim Yoho for his valuable assistance and comments during the preparation of the manuscript. Thanks are given to Dr. George Cline and Dr. Robert Carter assistance in statistical analyses. Thanks are given to the reviewers for their helpful comments.

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## PTERIDOPHYTES OF SOUTHEAST ALABAMA

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### ABSTRACT

Pteridophytes of southeast Alabama are represented by seventeen families, twenty-nine genera, fifty-nine specific and three hybrid taxa. Dryopteridaceae is represented by seven genera and ten taxa, Thelypteridaceae by three genera and seven species, Pteridaceae by three genera and six species, Ophioglossaceae by two genera and eight species, Lycopodiaceae by two genera and eight taxa, and Isoetaceae by one genus and seven species. Aspleniaceae is represented by one genus and three species. The families Blechnaceae, Osmundaceae, and Selaginellaceae are represented by one genus and two species each. The families Azollaceae, Dennstaedtiaceae, Equisetaceae, Lygodiaceae, Marsileaceae, Polypodiaceae, and Salviniaceae are represented by a single species each. The area delineated as southeast Alabama includes Barbour, Butler, Coffee, Conecuh, Covington, Crenshaw, Dale, Escambia, Geneva, Henry, Houston, and Pike counties. Dichotomous keys and descriptions are based upon material deposited in the herbarium of Troy University (TROY). Distribution records are based upon specimens deposited in the Troy University Herbarium (TROY), Auburn University Herbarium (AUA), and The University of Alabama Herbarium (UNA).

### INTRODUCTION

Pteridophytes are a group of vascular plants reproducing primarily through the production of spores. Four divisions (Psilotophyta, Lycopodiophyta, Equisetophyta, and Polypodiophyta) and twenty-five families of pteridophytes are known to occur in the United States (Flora of North America, 1993a; Flora of North America, 1993b). All four of these divisions contain native taxa in Alabama, and three of the divisions (Lycopodiophyta, Equisetophyta, and Polypodiophyta) have been reported from southeast Alabama.

Division Lycopodiophyta is represented by three families, thirteen species, and two hybrids in southeast Alabama. Division Equisetophyta is represented by one family and one species. Division Polypodiophyta is represented by thirteen families, forty-one species, and one hybrid in the study area.

Since 1960, three studies have addressed the pteridophytes of Alabama. *Ferns of Alabama and Fern Allies* (Dean, 1964), and the revised edition *Ferns of Alabama* (Dean,

1969) provide excellent illustrations and general information on the pteridophytes. However, the taxonomy, in many cases, is outdated and the distribution maps are incomplete. Short (1978), in his unpublished M.S. Thesis, *Distribution of Alabama pteridophytes*, produced the most comprehensive and detailed work on pteridophytes of the state. Although illustrations are not included, the dichotomous keys and county distribution maps are useful.

In the 25 or more years since these publications, additional county records have been added, as well as several species newly reported for Alabama. Therefore this publication is needed to adequately document the diversity and distribution of pteridophytes found in southeast Alabama. Spaulding *et al.* (2000, 2000b, 2001, 2001b, 2001c) recognized the need for a more current pteridophyte flora and published *Pteridophytes of Northeast Alabama and Adjacent Highlands*.

The objectives of this study were the development of dichotomous keys and county distribution maps for the pteridophytes of southeast Alabama.

DESCRIPTION OF STUDY AREA

The area delineated as southeast Alabama includes Barbour, Butler, Coffee, Conecuh, Covington, Crenshaw, Dale, Escambia, Geneva, Henry, Houston, and Pike counties (Fig. 1).



Figure 1. Map of Alabama with study areas highlighted.

The entire study area lies within the Coastal Plain Province and has an area of 2,664,849 ha. The northeast corner of Butler County and the northern sections of Crenshaw, Pike and Barbour counties are in the Blue Marl Region. Most of the central section of the study area occurs in the eastern and western portions of the Southern Red Hills. Houston County and parts of Geneva and Covington counties in the southeast section of the study area are in the Lime-Sink Region. The southwest section of the study area occurs primarily in the Southwestern Pine Hills. One exception is a small region of central and southeastern Conecuh County, which is located in the Lime Hills (Harper, 1943).

The topography of the study area ranges from low rolling hills in the north to flat or gentle sloping ridges in the south. Three major watersheds drain the study area. From east to west they include the Chattahoochee, Pea/Choctawhatchee, and the Conecuh (Mettee *et al.*, 1996).

The warm-temperate, moist climate of the study area has an average growing season ranging from 240 to 250 days. The Gulf of Mexico has a regulating effect on the climate and helps keep the temperature extremes at a minimum. The average annual temperature is approximately 20°C. Average temperatures during January, the coldest month, are 10.5°C, while July, the warmest month, averages 26°C. Precipitation ranges from 132 cm to 142 cm throughout most of the study area. The exception occurs in the southwestern section of the study area (Conecuh and Escambia counties) where the average ranges from 142 cm to 162 cm (Cartographic Research Laboratory, 2004).

## MATERIALS AND METHODS

This treatment includes all taxa of pteridophytes known to occur naturally and those that have become established and are reproducing in southeast Alabama. The dichotomous keys and descriptions are based upon material deposited in the herbarium of Troy University (TROY). Distribution records are based upon specimens deposited in the Troy University Herbarium (TROY), John D. Freeman Herbarium (AUA), and The University of Alabama Herbarium (UNA). Additional distribution data were obtained from Short (1978). With the exception of Isoetaceae and Lycopodiaceae, the nomenclature follows *Flora of North America* (Flora of North America Editorial Committee, 1993a).

## RESULTS

Pteridophytes of southeast Alabama are represented by seventeen families, twenty-nine genera, fifty-nine specific and three hybrid taxa. Dryopteridaceae is represented by seven genera and ten taxa, Thelypteridaceae by three genera and seven species, Pteridaceae by three genera and six species, Ophioglossaceae by two genera and eight species, Lycopodiaceae by two genera and eight taxa, and Isoetaceae by one genus and seven species. Aspleniaceae is represented by one genus and three species. The families Blechnaceae, Osmundaceae, and Selaginellaceae are represented by one genus and two species each. The families Azollaceae, Dennstaedtiaceae, Equisetaceae, Lygodiaceae,



Marsileaceae, Polypodiaceae, and Salviniaceae are represented by a single species each. Eight species are non-native.

KEY TO PTERIDOPHYTE FAMILIES

- 1. Stem hollow, jointed ..... Equisetaceae
- 1. Stem solid, not jointed ..... 2
  - 2. Leaves grass-like, root stock corm-like; plants of aquatic, semiaquatic, or vernal wet habitats..... Isoteaceae
  - 2. Leaves expanded blades or reduced scale-like structures; stems a rhizome or stolon; plants variously aquatic, terrestrial, or epiphytic ..... 3
- 3. Plants aquatic, free floating or rooted in mud..... 4
- 3. Plants terrestrial ..... 6
  - 4. Photosynthetic blades 4-parted and clover-like, widely spaced on long creeping rhizome at least partly rooted in substrate ..... Marsileaceae
  - 4. Photosynthetic blades round or oval, not clover-like, closely spaced on short free floating rhizome ..... 5
- 5. Leaves glabrous adaxially, blades 1.5 mm long .....Azollaceae
- 5. Leaves conspicuous pubescent adaxially, blades >1.0 mm long ..... Salviniaceae
  - 6. Plants moss-like in appearance; leaves <1.0 cm long ..... 7
  - 6. Plants not moss-like; leaves >1.0 cm long ..... 8
- 7. Plants slender; sterile leaves dimorphic, ligulate; heterosporous ..... Selaginellaceae
- 7. Plants coarse; sterile leaves monomorphic, aligulate; homosporous.... Lycopodiaceae
  - 8. Plants vine-like ..... Lygodiaceae
  - 8. Plants not vine-like ..... 9
- 9. Sporangia 0.5-1.0 mm in diameter; roots tuber-like, thick, fleshy .... Ophioglossaceae
- 9. Sporangia 0.08-0.1 mm in diameter; roots black, wiry ..... 10
  - 10. Stems short, erect, stout; roots matted, wiry ..... Osmundaceae
  - 10. Stems elongated rhizomes, creeping; roots scattered..... 11
- 11. Sori marginal, under reflexed margins of blade; indusium absent..... 12
- 11. Sori medial or submarginal but not under reflexed margins of blade; indusium present or absent ..... 13
  - 12. Rachis winged; pinnules opposite; >2.5 cm long..... Dennstaedtiaceae
  - 12. Rachis not winged; pinnules alternate, <2.5 cm long..... Pteridaceae
- 13. Sori without indusia..... 14
- 13. Sori with indusia ..... 15
  - 14. Fronds >25.0 cm long, many stipitate hairs and/or glands present, scales absent abaxially; sori <0.5 mm in diameter.....Thelypteridaceae
  - 14. Fronds <25.0 cm long, glands and stipitate hairs absent, scales present abaxially; sori >1.0 mm in diameter..... Polypodiaceae
- 15. Sori elongate, in 1 row on each side and immediately adjacent to costae or costules ..... Blechnaceae

- 15. Sori elongate to round, many per pinna, if elongate and parallel to costae then not ... immediately adjacent to them ..... 16
- 16. Petioles with 1 x-shaped or 2 back to back c-shaped vascular bundles; sori on one side of a vein ..... Aspleniaceae
- 16. Petioles with 2 u-shaped or 2-many circular vascular bundles arranged in an arch; sori at least partially on two sides of a vein ..... 17
- 17. Adaxial leaf surface pubescent, trichomes transparent; blade scales absent; petioles with 2 u-shaped vascular bundles ..... Thelypteridaceae
- 17. Adaxial leaf surface glabrous; blade scales present or absent; petioles with 2-many circular vascular bundles arranged in an arch ..... Dryopteridaceae

CHECKLIST OF PTERIDOPHYTES OF SOUTHEAST ALABAMA

ASPLENIACEAE (Spleenwort Family)

- Asplenium platyneuron* (Linnaeus) Britton, Sterns & Poggenburg--Ebony Spleenwort
- Asplenium resiliens* Kunze--Black-Stem Spleenwort
- Asplenium trichomanes* Linnaeus--Maidenhair Spleenwort

AZOLLACEAE (Mosquito Fern Family)

- Azolla caroliniana* Willdenow--Carolina Mosquito Fern

BLECHNACEAE (Chain Fern Family)

- Woodwardia areolata* (Linnaeus) T. Moore--Netted Chain Fern
- Woodwardia virginica* (Linnaeus) Smith--Virginia Chain Fern

DENNSTAEDTIACEAE (Bracken Fern Family)

- Pteridium aquilinum* (Linnaeus) Kuhn--Northern Bracken Fern

DRYOPTERIDACEAE (Wood Fern Family)

- Athyrium filix-femina* (Linnaeus) Roth ex Mertens--Subarctic Lady Fern
- Cyrtomium falcatum* (Linnaeus f.) C. Presl--Japanese Net-Vein Holly Fern
- Deparia petersonii* (Kunze) M. Kato--Peterson's-Spleenwort
- Dryopteris x australis* (Wherry) Small--Hybrid Wood Fern [*celsa* x *ludoviciana*]
- Dryopteris celsa* (W. Palmer) Knowlton, W. Palmer & Pollard--Log Fern
- Dryopteris ludoviciana* (Kunze) Small--Southern Wood Fern
- Onoclea sensibilis* Linnaeus--Sensitive Fern

*Polystichum acrostichoides* (Michaux) Schott--Christmas Fern

*Polystichum braunii* (Spenner) Fée--Braun's Holly Fern

*Woodsia obtusa* (Sprengel) Torrey--Blunt-Lobe Cliff Fern

### **EQUISETACEAE (Horsetail Family)**

*Equisetum hyemale* Linnaeus--Tall Scouring-Rush

### **ISOETACEAE (Quillwort Family)**

*Isoetes appalachiana* D. F. Brunton & D. M. Britton--Appalachian Quillwort

*Isoetes boomii* Luebke--Boom's Quillwort

*Isoetes flaccida* A. Braun--Southern Quillwort

*Isoetes hyemalis* D. F. Brunton--Evergreen Quillwort

*Isoetes louisianensis* Thieret--Louisiana Quillwort

*Isoetes melanopoda* Gay & Durieu--Black-Foot Quillwort

*Isoetes valida* (Engelman) Clute--True Quillwort

### **LYCOPODIACEAE (Club-Moss Family)**

*Lycopodiella alopecuroides* (Linnaeus) Cranfill--Fox-Tail Club-Moss

*Lycopodiella appressa* (Chapman) Cranfill--Southern Appressed Club-Moss

*Lycopodiella x brucei* Cranfill--Hybrid Club-Moss [*appressa* x *prostrata*]

*Lycopodiella caroliniana* (Linnaeus) Pichi Sermolli--Slender Club-Moss

*Lycopodiella cernua* (Linnaeus) Pichi Sermolli--Stag-Horn Club-Moss

*Lycopodiella x copelandii* (Eiger) Cranfill--Hybrid Club-Moss [*alopecuroides* x *appressa*]

*Lycopodiella prostrata* (Harper) Cranfill--Feather-Stem Club-Moss

*Lycopodium digitatum* Dillenius ex A. Braun--Fan Ground-Pine

### **LYGODIACEAE (Climbing Fern Family)**

*Lygodium japonicum* (Thunberg ex Murray) Swartz--Japanese Climbing Fern

### **MARSILEACEAE (Water-Clover Family)**

*Marsilea minuta* Linnaeus--Dwarf Water-Clover

### **OPHIOGLOSSACEAE (Adder's-Tongue Family)**

*Botrychium biternatum* (Savigny) L. Underwood--Sparse-Lobe Grape Fern

*Botrychium dissectum* Sprengel--Cut-Leaf Grape Fern

*Botrychium lunarioides* (Michaux) Swartz--Winter Grape Fern



*Botrychium virginianum* (Linnaeus) Swartz--Rattlesnake Fern  
*Ophioglossum crotalophoroides* Walter--Bulbous Adder's-Tongue  
*Ophioglossum engelmannii* Prantl--Limestone Adder's-Tongue  
*Ophioglossum nudicaule* Linnaeus--Least Adder's-Tongue  
*Ophioglossum petiolatum* Hooker--Long-Stem Adder's-Tongue

### **OSMUNDACEAE (Royal Fern Family)**

*Osmunda cinnamomea* Linnaeus--Cinnamon Fern  
*Osmunda regalis* Linnaeus--Royal Fern

### **POLYPODIACEAE (Polypody Fern Family)**

*Pleopeltis polypodioides* (Linnaeus) E. G. Andrews & Windham--Resurrection Fern

### **PTERIDACEAE (Maidenhair Fern Family)**

*Adiantum capillus-veneris* Linnaeus--Southern Maidenhair  
*Adiantum pedatum* Linnaeus--Northern Maidenhair  
*Cheilanthes lanosa* (Michaux) D. C. Eaton--Hairy Lip Fern  
*Pteris cretica* Linnaeus--Cretan Brake  
*Pteris multifida* Poiret--Spider Brake  
*Pteris vittata* Linnaeus--Ladder Brake

### **SALVINIACEAE (Water Fern Family)**

*Salvinia minima* Baker--Water-Spangles

### **SELAGINELLACEAE (Spike-Moss Family)**

*Selaginella apoda* (Linnaeus) Spring--Meadow Spike-Moss  
*Selaginella ludoviciana* (A. Braun) A. Braun--Gulf Spike-Moss

### **THELYPTERIDACEAE (Maiden Fern Family)**

*Macrothelypteris torresiana* (Gaudichaud Beaupré) Ching--False Maiden Fern  
*Pliogopteris hexagonoptera* (Michaux) Fée--Broad Beech Fern  
*Thelypteris dentata* (Forsskål) E. P. St. John--Downy Maiden Fern  
*Thelypteris hispidula* (Decaisne) C. F. Reed--Rough-Hairy Maiden Fern  
*Thelypteris kunthii* (Desvaux) C. V. Morton--Kunth's Maiden Fern  
*Thelypteris ovata* R. P. St. John--Ovate Marsh Fern  
*Thelypteris palustris* Schott--Eastern Marsh Fern

## ACKNOWLEDGEMENTS

We thank the curators of herbaria at Auburn University (AUA) and The University of Alabama (UNA) for providing useful information during this study and making us welcome during our visits.

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## HETEROGENOUS MODELING AND SIMULATION OF ACTIVATED SLUDGE PROCESSES

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### ABSTRACT

A simulation model of an activated sludge processes reactor was developed considering mass transfer balance and the three growth processes: carbon oxidation, nitrification, and denitrification. Helwan wastewater treatment plant (WWTP) was used to extract the suitable stoichiometric and kinetic parameters to be used for the simulation. Helwan WWTP was used to simulate the removal efficiency of the biochemical oxygen demand (BOD) substrate and ammonia. The average error of the removal efficiency in Helwan WWTP reached 3.311 % for the substrate and 12.521 % for the ammonia. Zenine WWTP was used for the testing and validation of the process model through predicting the response of substrate only where the average error of the removal efficiency of substrate reached 4.634 %. A parametric study of the activated sludge was performed taking into account the effects of recycle ratio, flow rate, and influent substrate concentrations on the removal efficiency of the aeration tank. It was found that the removal efficiency of substrate and ammonia was increased by increasing of recycle ratio, influent substrate concentrations and also increased by decreasing influent flow rates. It was found that the sludge age increased by increasing the recycle ratio and decreased by decreasing the influent flow rates.

### INTRODUCTION

Simulation models of the activated sludge process are believed to be a useful tool for research, process optimization, and troubleshooting at full-scale treatment plants. Activated sludge is a complex dynamic process; and simulation of such process must necessarily account for a large number of reactions between a large number of components. There is a need for simulation models that describe the dynamic behavior of the activated sludge process. However, implementing a model to simulate most treatment plants is limited due to a lack of accurate input parameter values required by the models. To improve the operating efficiencies of current wastewater treatment plants, both municipal and industrial engineers have looked to automatic process control.



Figure 1 shows a schematic diagram of the activated sludge process where aeration basins (reactors) are typically open tanks containing equipment to provide aeration and to provide sufficient mixing energy to keep the biomass in suspension. The depth is mainly determined by energy transfer and mixing characteristics, and usually ranges from 3 to 7.5m (Grady 1990). A single piece of equipment such as diffused air, mechanical surface aerator, or jet aerator is used in many cases to provide aeration and keep the solids in suspension. Auxiliary mechanical mixers are used when the aeration does not provide sufficient mixing energy.

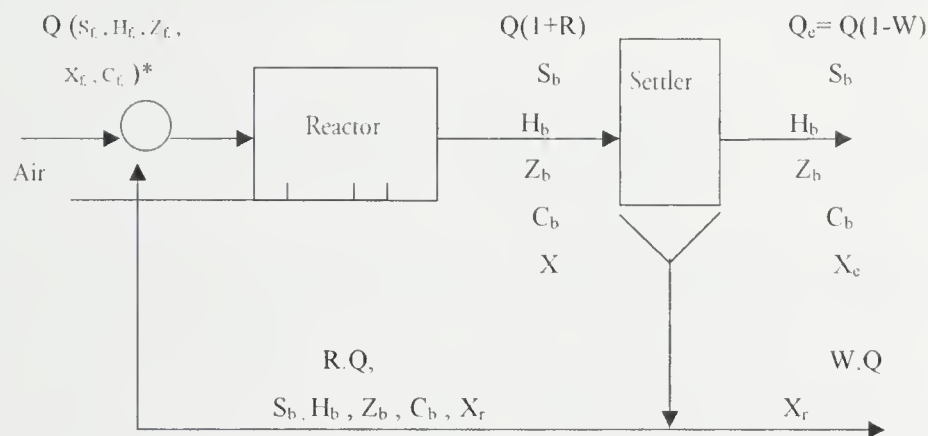


Figure 1. Schematic diagram of the activated sludge process.

\*Purge Fraction (W), Influent Volumetric Flow Rate (Q), Recycled Volume Flow Rate (QR), Total Volume (V), Recycle Ratio QR/Q (R), Substrate Component Mass (S0) Substrate Feed Concentration (Sf), Soluble Substrate Concentration (Ss), Substrate Output From The Reactor (Sb), Biomass Component Mass (X), Biomass Feed Concentration (Xf), Recycled Biomass Concentration (Xr) Effluent Biomass Concentration (Xe), Biomass Rate Of Reaction (r), Ammonia Component Mass (H), Ammonia Feed Concentration (Hf), Ammonia Soluble Concentration (Hs), Ammonia Output From The Reactor (Hb), Nitrate Component Mass (Z), Nitrate Feed Concentration (Zf), Nitrate Soluble Concentration (Zs), Nitrate Output From The Reactor (Zb), Oxygen Component Mass (C), Oxygen Feed Concentration (Cf), Oxygen Soluble Concentration (Cs), Oxygen Output From The Reactor (Cb), Substrate Growth Rate Coefficient (Kgs), Ammonia Growth Rate Coefficient (Kgh), Oxygen Growth Rate Coefficient (Kgc), Nitrate Growth Rate Coefficient (Kgz).

The secondary clarifier performs two functions in the activated sludge process. The first function, clarification, is the separation of the biomass from the treated wastewater to produce a clarified effluent that meets the effluent suspended solids goal. The other is the thickening of sludge for return to the bioreactor. Since both functions are affected by clarifier depth, the design depth must be selected to provide an adequate volume for both functions (Tchobanoglous and Burton, 1991, Jack, 2001). For instance, the volume must be sufficient to store the solids during periods of high flow. The objectives of this study thus are:

1. To build a process model considering mass transfer balance and simulates an Egyptian plant, Helwan wastewater treatment plant, that exists in the south of Cairo and has a capacity of 350000 m<sup>3</sup> /d and average removal efficiency of 85%

for substrate and 62% for ammonia. To assess the simulation results, the model validation was performed for Zenine wastewater treatment plant that exists in the west of Cairo and has a capacity of 330000 m<sup>3</sup> /d and average removal efficiency of 87.6% for substrate.

2. To adjust the model kinetic parameters of the biochemical reactions of the three growth processes: carbon oxidation, nitrification, and denitrification under the effect of mass transfer conditions for the simulation purpose.
3. To study the effect of the operating conditions such as flow rate, recycle ratio, and feed substrate concentrations on the removal efficiency of both substrate and ammonia.

## **ACTIVATED SLUDGE PROCESSES MODEL DEVELOPMENT**

The key to a successful modeling of the activated sludge process is the appropriate assumptions to achieve a compromise between complexity and utility. In the present study we have derived the general dynamic model of the activated sludge process in the bioreactor. The bioreactor (aeration basin) model describes the removal of organic matter, nitrification, and denitrification. The derived bioreactor model is an extension of the activated sludge model number 1 (ASM1). It is a biofloc model, developed in Henze et al. (1987), considering both the mass transfer and biochemical process reactions. The simulation model considers the four main components: BOD (readily biodegradable substrate (S), ammonia (H), Nitrate (Z), and oxygen (C). The assumptions in the biofloc model and the process model are:

1. The power input used in the bioreactor is assumed to equal 80% of the maximum value to realize a complete mixing in the reactor.
2. The effluent biomass concentration is neglected.
3. The consumption of substrate, ammonia, and oxygen in the settler is neglected.
4. The average volumetric flow rate of the influent is constant.
5. The average recycle ratio and wastage ratio are not neglected.

The details of the process model developed are shown in Fig. 1.

## **DERIVATION OF THE PROCESS MODEL**

The equations of substrate is considered by applying mass balance on the settler in order to get the biomass concentration exiting, which is recycled to the bioreactor. Next, the mass balance equations of the bioreactor will be derived. The following are the variables used in the derivation ( see Fig. 1):

$W$ = purge fraction

$Q$  = influent volumetric flow rate

$Q_R$ =recycled volume flow rate

$V$ = total volume

$R$ = recycle ratio =  $Q_R/Q$

$S$ = substrate component mass

$S_f$ = substrate feed concentration

$S_s$ = soluble substrate concentration

$S_b$ = substrate output from the reactor

$X$ = biomass component mass

$X_f$ = biomass feed concentration

$X_r$ = recycled biomass concentration

$X_e$ = effluent biomass concentration

$r_x$  = biomass rate of reaction

$H$ = ammonia component mass

$H_f$ = ammonia feed concentration

$H_s$ = ammonia soluble concentration

$H_b$ = ammonia output from the reactor

$Z$ = nitrate component mass

$Z_f$ = nitrate feed concentration

$Z_s$ = nitrate soluble concentration

$Z_b$ = nitrate output from the reactor

$C$ = oxygen component mass

$C_f$ = oxygen feed concentration

$C_s$ = oxygen soluble concentration

$C_b$ = oxygen output from the reactor

$K_{gs}$  = substrate growth rate coefficient

$K_{gh}$  = ammonia growth rate coefficient

$K_{gc}$  = oxygen growth rate coefficient

$K_{gz}$  = nitrate growth rate coefficient

Applying a component mass balance on biomass for the settler gives:

$$Q(1 + R)X = Q(R + W)X_r + Q_e X_e \quad (1)$$

Neglecting the effluent biomass concentration,  $X_e=0$ , then,

$$X_r = \left( \frac{1 + R}{R + W} \right) X \quad (2)$$



By performing mass balance on the reactor, the following equations are obtained:

### 1. Component Mass Balance on Substrate (S)

Neglecting the substrate consumption in the settling tank and assuming a substantial decrease in the water content of the settled sludge, related to that measured, lead to  $S_{\text{before settler}} = S_{\text{after settler}}$ . Applying a component mass balance on the substrate for the bioreactor gives:

$$\text{Inflow} = \text{Outflow} + \text{Net growth} + \text{Accumulation}$$

$$Q S_f + RQ S_b = Q(1 + R) S_b + K_{gs} A_{tf} (S_b - S_s) + V \frac{dS_b}{dt} \quad (3)$$

$$\frac{V}{Q} \frac{dS_b}{dt} = S_f - S_b - \frac{K_{gs} A_{tf}}{Q} (S_b - S_s) \quad (4)$$

### 2. Component Mass Balance on Ammonia (H)

Ammonia nitrogen can be removed from wastewater by volatilization of ammonia. Gas stripping is most effective when contaminated wastewater is exposed to air. Hence, this process is considered by adding a factor of ammonia stripping ( $G_f$ ) in the differential equation of ammonia mass balance. Applying a component mass balance on ammonia for the bioreactor gives:

$$\frac{V}{Q} \frac{dH_b}{dt} = H_f - H_b - G_f \frac{K_{gh} A_{tf}}{Q} (H_b - H_s) \quad (5)$$

### 3. Component Mass Balance on Nitrate (Z)

Applying a component mass balance on nitrate for the bioreactor gives:

$$\frac{V}{Q} \frac{dZ_b}{dt} = Z_f - Z_b - \frac{K_{gz} A_{tf}}{Q} (Z_b - Z_s) \quad (6)$$

### 4. Component Mass Balance on Oxygen (C)

Applying a component mass balance on oxygen for the bioreactor gives:

$$\frac{V}{Q} \frac{dC_b}{dt} = C_f + \frac{V}{Q} K_l a (C^* - C_b) - C_b - \frac{K_{gc} A_{tf}}{Q} (C_b - C_s) \quad (7)$$

### 5. Component Mass Balance on Biomass (X)

Applying a component mass balance on biomass for the bioreactor gives:

$$QX_f + RQ \left( \frac{I + R}{R + W} \right) X = Q(I + R) X - r_x V + V \frac{dX}{dt} \quad (8)$$

Hence,

$$\frac{V}{Q} \frac{dX}{dt} = X_f + \frac{V}{Q} r_x + \frac{W(I + R)}{(W + R)} X \quad (9)$$

From task group (Henze et al. 1987) the rate of reaction of heterotrophic and autotrophic biomass can be obtained as follows:

$$\begin{aligned} r_x = & \mu_H \left( \frac{S_b}{K_s + S_b} \right) \left( \frac{C_b}{K_{oH} + C_b} \right) + \eta_g \mu_H \left( \frac{S_b}{K_s + S_b} \right) \left( \frac{K_c}{K_c + C_b} \right) \left( \frac{Z_b}{K_z + Z_b} \right) \\ & + \mu_A \left( \frac{H_b}{K_h + H_b} \right) \left( \frac{C_b}{K_{cA} + C_b} \right) - b_H - b_A \end{aligned} \quad (10)$$

These dynamic model equations are first order differential equations.

#### Solution Technique

The initial value problem given by equations (4)-(9) are solved by any of the standard numerical methods for a system of ordinary differential equations using the finite difference technique. A large number of points have been taken to improve the accuracy of the results.

## RESULTS AND DISCUSSION

Selecting suitable kinetic and stoichiometric parameters is considered by using Helwan WWTP data. The model is tested by carrying out the simulation on Helwan WWTP on substrate BOD and ammonia concentrations. Zenine WWTP was used for the testing and validation of the process model through predicting the response of substrate only as will be shown.

## Parameters Evaluation

Shieh and Leo (1986) used an experimental procedure for determination of intrinsic kinetic coefficients. The experimental apparatus, rotating disk biofilm reactor, provides a relatively simple yet rigorous means for examination of both intrinsic and mass transfer limited kinetics. It allows for direct measurement of intrinsic kinetic coefficients and biological parameters relevant to a given reaction. The intrinsic kinetic coefficient of biological denitrification measured in their study is  $K_z = 2.875 \text{ mg NO}_3\text{-N}_2/\text{d}$ , and nitrate-nitrogen effective diffusivity  $De = 0.815 \times 10^{-5} \text{ cm}^2/\text{sec}$ .

Alison et al. (1993) measured the maximum specific growth rate  $\mu_{\max}$  and the half saturation coefficient ( $K_s$ ). A simple respirometric technique was used where different volumes of concentrated wastewater were contacted with biomass and the response measured as a change in oxygen uptake rate  $\Delta\text{OUR}$ . The  $\Delta\text{OUR}$  was then related to the growth rate, and a series of substrate concentrations and growth rate relationships were determined, and from which  $\mu_{\max}$  and  $K_s$  were calculated. Typical  $\mu_{\max}$  and  $K_s$  values published for municipal sewage are in the range  $\mu_{\max} = 1\text{-}5 \text{ d}^{-1}$ , with a typical value of  $2.5 \text{ d}^{-1}$  (Metcalf and Eddy, 1990). The range  $K_s$  is  $6\text{-}19 \text{ mg l}^{-1}$  with a typical value of  $12 \text{ mg l}^{-1}$ .

Yerachmiel et al. (1990) carried out bench-scale experiments using domestic wastewater under a constant flow rate. They obtained a set of kinetic and stoichiometric coefficients with BOD removal and nitrification only. The denitrification process was not tested. The set of measured coefficients falls within the range reported in the literature for domestic wastewater. Differences in some of the values may be attributed to the selection of decreased diffusional mass transfer kinetics in systems.

The component mass balance equations on the substrate, ammonia, nitrate, oxygen, autotrophic and heterotrophic biomass derived above are considered to extract the best values of parameters to simulate Helwan plant performance. Many points were taken from Helwan wastewater treatment plant data to obtain the optimum result at which the theoretical predictions (the output of the simulation model program) are very close to the measured results (the output from Helwan WWTP). The data shown in Table 1 are used as input for the model program. The suitable parameters in turn will be used for the validation and simulation of Zenine WWTP. Table 1 shows the average measured values of process parameters for Helwan WWTP.

Selecting kinetic and stoichiometric parameters using the literature data, depending on ASM1 at first, can validate the model. However, in order to achieve acceptable agreement between the real and theoretical concentrations, numerical estimation of some parameters is necessary. To simplify this procedure, the relations between the effluent concentrations of the components and the kinetic and stoichiometric coefficients used in the model should be known. It was found that the effluent concentration of substrate, ammonia are directly proportional to the values of the saturation coefficients  $K_s$ ,  $K_A$ ,  $K_{CA}$  and yield coefficients  $Y_H$  and  $Y_A$ . Also, it was found that they are inversely proportional to growth rates  $\mu_H$  and  $\mu_A$ . These relations are very useful to reach the best values of kinetic and stoichiometric coefficients that make the theoretical results comparatively much closer to that of the actual results.



Table 1. Average values of process parameters for Helwan plant

Parameter	Value
Qo (m3/day) (inlet flow)	43750
%R	60
%W	3.5
Sf (mg/l) (BOD )	83
Hf (mg/l) (ammonia)	1.03
Zf (mg/l) (nitrate)	11
SVI (ml/gm)	57
(P/V) (W/m3 )	109.7
V (m3) ( reactor volume)	3000
Xf (mg/l) (biomass)	50

**R= recycle ratio, W= purge fraction, S= substrate component mass, Sf= sustrate feed concentration, Hf= ammonia feed concentration, Zf= nitrate feed concentration, SVI= substarte concentrarion, and P/V= power input per liquid volume.**

The values given in Table 2 are considered typical for neutral pH and domestic wastewater. The selected values of the kinetic and stoichiometric coefficients shown in Table 2 represent a set of values that result in a good fit of the experimental data and the model prediction. The following are some observations on the values shown in Table 2:

1. Some parameters such as  $C_{\text{saturated}} = 9.8 \text{ mg/l}$ , density, diffusivities, viscosity, are adopted from the literature.
2. Diffusivity inside flocs is assumed to be 80% of that in pure water.
3. Some parameter values such as  $\mu_{\text{H}}$  and  $\mu_{\text{A}}$  are within the same range of the ASM1 model adopted by Henze et al.1987.
4. Some parameter values such as  $K_{\text{S}}$ ,  $K_{\text{A}}$ , and  $K_{\text{CH}}$  are out of the range of ASM1 model ( Henze et al., 1987) due to considering the mass transfer limitations.
5. The study of parametric sensitivity of the model has shown that the influence of the parameters  $Y_{\text{A}}$  and  $K_{\text{A}}$  is not large on the effluent concentration of ammonia. It can be explained that the fraction of the autotrophs that oxidize ammonia in aerobic growth process to the heterotrophs is very small, so the effluent ammonia is more sensitive to  $\mu_{\text{H}}$  and  $b_{\text{H}}$  than  $\mu_{\text{A}}$  and  $b_{\text{A}}$  for the same reason.
6. The assumed value for ammonia stripping factor  $G_{\text{F}} = 0.075$  is very small and suitable because of simultaneous loss of ammonia due to practical conditions

- such as agitation, temperature, and exposed surface area in addition to non-adding any chemicals such as lime inside the aeration basin.
7. The assumed value for  $\eta_g$  is taken from the literature.
  8. The range of experimental values for the ratio of active biomass in flocs is nearly 0.8.
  9. This makes the effluent of biomass 2.2 – 3 gm / l.

**Table 2. The parameter values extracted from the floc model**

Symbol	Value	Explanation
$Y_A$	0.55	Yield for autotrophic biomass
$Y_H$	0.7	Yield for heterotrophic biomass
$\mu_A$	0.42 day <sup>-1</sup>	Maximum specific growth rate for autotrophic biomass
$\mu_H$	4.35 day <sup>-1</sup>	Maximum specific growth rate for heterotrophic biomass
$K_S$	220 mg l <sup>-1</sup>	half saturation coefficient for heterotrophic biomass
$K_{c1}$	0.05 mg O2 l <sup>-1</sup>	Oxygen half saturation coefficient for heterotrophic biomass
$K_z$	0.15 mg NO <sub>3</sub> -N l <sup>-1</sup>	Nitrate half saturation coefficient for denitrifying heterotrophic biomass
$K_A$	250 g NH <sub>3</sub> -N l <sup>-1</sup>	Ammonium half saturation coefficient for autotrophic biomass
$K_{c2}$	2 mg O2 l <sup>-1</sup>	Oxygen half saturation coefficient for autotrophic biomass
$b_A$	0.08 day <sup>-1</sup>	Decay rate coefficient for autotrophic biomass
$b_H$	0.62 day <sup>-1</sup>	Decay rate coefficient for heterotrophic biomass
$\eta_g$	0.8	Correction factor for $\mu_H$ under anoxic conditions
$K_{La}$		Volumetric oxygen transfer coefficient see Chapter 2
$C^*$	9.8 mg/l	Saturated oxygen concentration

**MODEL TESTING**

Min et al. (1997) performed some trials for a coke wastewater treatment plant by fixed biofilm system for COD and NH<sub>3</sub>-N removal. The experimental results showed that this system was efficient and stable in COD and NH<sub>3</sub>-N<sub>2</sub> reductions. The effluent COD and NH<sub>3</sub>-N<sub>2</sub> were 114 and 3.1 mg/l with removal efficiency of 92.4 and 98.8 % respectively.

In order to test the accuracy of the values obtained for the parameters, numerical runs of the model have been carried out for the simulation model using the parameters obtained for the model and the constants that define the characteristics of the system. The model proposed in this work was tested. Helwan WWTP data, which were used for the extraction of kinetic and stoichiometric coefficient, shown in Table 2, are also used in order to test the model. The theoretical results (or the model predictions) in terms of the effluent concentrations were compared against the field results of Helwan plant .

**Helwan WWTP Aeration Basin**

The operating data for Helwan aeration basin are:

- 1. The aeration basin volume =3200 m<sup>3</sup>.
- 2. Cross sectional area =806.88 m<sup>2</sup>.
- 3. Volumetric Flow rate=43,750 m<sup>3</sup>/day.
- 4. Average recycle ratio =30-120% of the feed.
- 5. Average wastage ratio = 0.1-5.% of the feed.
- 6. The power input in (W/m<sup>3</sup>) for the aeration basin = 200 kW on the basis of 80% of the available maximum power input.
- 7. The technique of the aeration used in the plant is mechanical surface aeration whereby the wastewater is agitated at the surface to promote the transfer of oxygen to the water from the atmosphere above the liquid . The surface aerators also throw water into the air to increase contact area. The agitator type used is a cone turbine with 16 blades.
- 8. Available volumetric flow rate of air =1246.36 m<sup>3</sup>/hr.
- 9.  $K_{la}$  is a function of power input per m<sup>3</sup> of liquid volume (P/V) in the aeration basin:

$$K_{la} = \frac{K_{la \max} \cdot (P / V)}{(P / V) + k} \tag{11}$$

Where V=occupied reactor volume=1822.91 m<sup>3</sup> and P=200 kW. Hence, P/V=109.71 W/m<sup>3</sup> and by fitting  $K_{la \max} = 500 \text{ day}^{-1}$ ,  $k=450$  , and  $K_{la}=98.01 \text{ day}^{-1}$

**Simulation Results for Helwan WWTP**

Because the effluent BOD and ammonia field data is noisy, it can only serve as a rough guide for evaluating the model behavior (Lessard and Beck, 1993). Considering the previous operating data for the northern aeration basin for Helwan WWTP in the simulation model, for readily biodegradable substrate BOD (S) and ammonia (H), the results shown in Tables 3 and 4 were obtained.

Where the average removal efficiency error equals the real removal efficiency, and the theoretical removal efficiency is defined as:

$$\left| \frac{S_{out \text{ real}} - S_{out \text{ theo}}}{S_f} \right| * 100 \tag{12}$$



Table 3. Simulation results for Helwan plant in Feb 1996

Date	Feed			S <sub>out</sub>		H <sub>out</sub>		%Average Removal Error	
	S <sub>f</sub> (mg/l)	H <sub>f</sub> (mg/l)	SVI (ml/g)	Real	Theo.	Real	Theo.	%S	%H
3/2/96	83	11	57	12	12.075	5.3	5.593	0.01	2.67
10/2	83	12.5	56	14	12.076	3	6.3	2.32	26.4
13/2	90	13.1	56	20	12.7	11	6.67	8.11	33.1
16/2	88	12.3	57	14	12.526	4.5	6.25	1.7	14.23
21/2	69	12	47	17	11	5.3	6.8	8.75	12.5
26/2	69	11.3	53	10	10.68	3	5.8	1	24.78
Average error								3.65	18.95

S<sub>f</sub>= sustrate feed concentration, H<sub>f</sub>= ammonia feed concentration, SVI= substarte concentrarion, S= substrate component mass, and H= ammonia component mass

Table 4. Simulation results for Helwan plant in March 1996.

Date	Feed			S <sub>out</sub>		H <sub>out</sub>		%Average Removal Error	
	S <sub>f</sub> (mg/l)	H <sub>f</sub> (mg/l)	SVI (ml/g)	Real	Theo.	Real	Theo.	%S	%H
2/3	221	18.8	57	31	20.46	10.6	11.15	4.77	4.7
6/3	427	20.6	54	39	47	11.9	13.47	2.82	7.62
11/3	266	20.3	56	34	41.9	15.6	13.23	2.97	11.4
23/3	280	15.4	57	48	54.33	10.2	10.1	2.3	0.65
30/3	248	23.3	47	28	23.348	12.5	13.9	2	6
Average error								2.972	6.074

S<sub>f</sub>= sustrate feed concentration, H<sub>f</sub>= ammonia feed concentration, SVI = substarte concentrarion, S= substrate component mass, and H= ammonia component mass.

It is noted from Tables 3 and 4 that the theoretical and real values of readily biodegradable substrate BOD (S) are in close agreement. This result gives a good indication for model capability to simulate BOD effluent and suggests that the inclusion of mass transfer effects in the floc model will be useful in better describing real dynamic behavior of the removal efficiency or the effluent quality.

The theoretical and real effluent ammonia concentration (H<sub>out</sub>) values as shown in Tables 3 and 4 are not in close agreement. The average removal error of both the substrate (BOD) and ammonia are 3.311 and 12.521% respectively. The difference between the real and theoretical results may be due to the finite accuracy of the numerical method used.

The average removal error between the theoretical and real values of ammonia (H) comes from the air stripping operation, where the assumed value of the air stripping factor may not be accurate enough to express the real amount which was lost when exposed to free air. In fact, for a real plant the stripping factor is not constant but depends on the practical situations. The average removal error between the theoretical and real values is as shown in the range of 6-19%.

## MODEL VALIDATION

Helwan WWTP was used for extraction of kinetic and stoichiometric coefficient as shown in Table 2 and used also for testing the model. However, Zenine WWTP is used for validation of the model using the same kinetic and stoichiometric coefficient as shown in Table 9. Zenine WWTP is located in the west of Cairo. It treats wastewater at a capacity of 330,000 m<sup>3</sup>/day. It consists of 3 modules, each one containing 22 aeration basins. They have the same total volume, method of aeration and working conditions. It is noted that the volumes of the aeration basins in Zenine WWTP are smaller than that of Helwan WWTP but their numbers in Zenine WWTP are greater.

### ZenineWWTP Aeration Basin

The operating data for ZenineWWTP aeration basin are:

1. The aeration basin volume = 537 m<sup>3</sup>.
2. Cross sectional area = 50 m<sup>2</sup>.
3. Volumetric flow rate = 5,000 m<sup>3</sup>/day.
4. Average recycle ratio = 90% of the feed.
5. Average wastage ratio = 0.5 – 5.0% of the feed.
6. The power input in (W/m<sup>3</sup>) for the aeration basin = 40.33 kW on the basis of 75 % of the available maximum power input.
7. The technique of aeration method used in the plant is the diffused air technique, whereby the air is introduced below the surface through diffusers or nozzles. The rise velocity of the bubbles creates a circulating mixing pattern in the liquid.
8. Available volumetric flow rate of air = 1227.3 m<sup>3</sup>/h.
9. Evaluation of  $K_{la}$  in the same as above, using the same correlation (11), where  $V = 208.33$  m<sup>3</sup> and  $P = 40.33$  kW, hence,  $P/V = 193.6$  W/m<sup>3</sup>. By fitting it is found that  $K_{la\ max} = 500$  day<sup>-1</sup>,  $K = 450$  and  $K_{la} = 150.41$  day<sup>-1</sup>

### Simulation Results for Zenine WWTP

The previous operating data of the aeration basin in module 3 for Zenine WWTP and stoichiometric and kinetic parameters shown in Table 2 are used to validate the simulation model. Readily biodegradable substrate BOD (S) only is used for the purpose of validation because of unavailable data for other components such as ammonia. The simulation model was applied for 12 months in 1994 for BOD. Tables 5-10 show some

simulation results for Zenine WWTP.

From these tables it can be shown that the percentage average removal error of the removal efficiency of substrate (BOD) between the real and theoretical results of Zenine WWTP equals 4.634%. Also, the results show that the theoretical and the real values of substrate (BOD) are in close agreement. The difference between the real and theoretical results is due to the finite accuracy of the numerical method used. These results give a good impression that the model is able to predict the output of the aeration tank in a wastewater treatment plant. This emphasizes the validation of the model and also the accuracy of the kinetic parameters.

**Table 5. Simulation results for Zenine plant in January 1994**

Date	$S_f$	SVI	$S_{out}$		%Average Removal Eff. Error (%S)
			Real	Theo.	
1/1	119	130	16	17.4	1.2
5/1	146	129	15	19.4	3.01
9/1	133	141	16	18.5	1.9
15/1	124	152	16	17.8	1.45
21/1	138	132	16	18.9	2.2
26/1	132	120	17	18.4	1
Average error					2.152

$S_f$ = sustrate feed concentration, SVI= substarte concentrarion, and S= substrate component mass.

**Table 6. Simulation results for Zenine plant in March 1994**

Date	$S_f$	SVI	$S_{out}$		%Average Removal Error (%S)
			Real	Theo.	
1/3	127	128	20	17.72	1.8
5/3	160	144	23	18.9	2.5
13/3	174	164	24	20.6	2
17/3	166	144	22	20.2	1.1
22/3	110	101	14	16.3	2.1
31/3	135	122	30	18.3	8.67
Average error					3.03

$S_f$ = sustrate feed concentration, SVI= substarte concentrarion, and S= substrate component mass.

**Table 7. Simulation results for Zenine plant in May 1994**

	$S_f$	SVI	$S_{out}$		%Average Removal Eff. Error (%S)
			Real	Theo.	
2/5	130	91	15	18.3	2.54
4/5	137	95	20	18.8	1
6/5	111	96	13	16.7	3.33
10/5	112	111	18	16.89	1
15/5	117	119	18	17.3	1.5
	141	143	29	19.1	7.02
26/5	160	119	27	20.31	4.2
31/5	103	150	11	16.1	4.95
Average error					3.2

$S_f$ = sustrate feed concentration, SVI= substarte concentrarion, and S= substrate component mass

**Table 8. Simulation results for Zenine plant in July 1994**

Date	$S_f$	SVI	$S_{out}$		%Average Removal Eff. Error (%S)
			Real	Theo.	
1/7	147	141	44	18.2	17.55
4/7	95	133	11	14.8	4
7/7	121	116	5	16.5	9.5
10/7	101	106	10	14.5	4.45
13/7	93	91	35	14.9	21.6
19/7	127	142	20	16.94	2.9
25/7	109	175	16	15.6	0.36
31/7	140	231	8	17.8	7
Average error					8.42

$S_f$ = sustrate feed concentration, SVI= substarte concentrarion, and S= substrate component mass.

**Table 9. Simulation results for Zenine plant in September 1994**

Date	$S_f$	SVI	$S_{out}$		%Average Removal Eff. Error (%S)
			Real	Theo.	
1/9	131	98	20	18.1	1.53
5/9	109	122	19	16.3	2.5
8/9	110	133	14	16.64	2.4
15/9	119	138	11	17.2	5.21
22/9	99	193	9	15.5	5.57
25/9	102	217	10	15.5	5.24
30/9	133	203	10	18.2	6.2
Average error					4.05

$S_f$ = sustrate feed concentration, SVI= substarte concentrarion, and S = substrate component mass.



**Table 10. Simulation results for Zenine plant in December 1994**

Date	S <sub>f</sub>	SVI	S <sub>out</sub>		%Average Removal Eff. Error (%S)
			Real	Theo.	
1/12	144	95	24	15.8	5.7
5/12	119	98	13	15.4	2
11/12	105	97	11	14.8	3.62
17/12	121.7	89	28	21	5.75
25/12	104	122	29	14.7	13.75
31/12	130	190	10	15	3.85
Average error					5.78

S<sub>f</sub>= sustrate feed concentration, SVI= substarte concentarion, and S= substrate component mass.

**Parametric Study of Activated Sludge Process**

The parametric study is conducted to evaluate the performance of the aeration basin in the activated sludge plants. This is performed by studying the effect of the following operating parameters: influent flow rate, recycle ratio, wastage ratio, power input and influent composition of substrate and biomass on removal efficiency of the substrate (BOD) and ammonia. Yuichi et al. (1992) studied the effect of the operational performance on percentage nitrogen removal efficiency by a single-stage, single-sludge activated sludge process. They found that more than 97% of the organic carbon was removed and only small concentrations of the NH<sub>4</sub>-N<sub>2</sub> were found in the effluent.

The data shown in Table 1 and the kinetic and stoichiometric coefficients shown in Table 2 will be considered. When the effect of one parameter is studied the other parameters are kept constant. In our study we defined:

Removal efficiency of substrate =  $\frac{S_f - S_{out}}{S_f} * 100$  (13)

Removal efficiency of ammonia =  $\frac{H_f - H_{out}}{H_f} * 100$  (14)

Sludge age,  $\theta_c$ , is defined as the ratio of biomass in the reactor to the net rate of biomass. It is often called solids retention time in the reacting system. It has a principal effect on the performance and the capabilities of an activated sludge system. It is important in activated sludge systems because it is an operational parameter that can be physically controlled to maintain treatment performance. Lawrence and McCarty's (1970) landmark paper linked the sludge age to the treatment efficiency thereby providing means of maintaining treatment

performance by manipulating physical attributes such as wastage rate.

At steady state conditions, the net rate of biomass generation is equal to the rate at which biomass flows out of the system. If biomass is removed by wasting from the recycle line and by losses in the clarifier overflow, the sludge age, as shown in Fig. 1, is given by:

$$\theta_c \text{ (d)} = \frac{VX}{QWX_r + Q_e X_e} = \frac{V(R + W)}{QW(1 + R)} \quad (15)$$

where  $X_e = 0.0$ . Through experience, operators of conventional activated sludge reactors have found that  $\theta_c$  usually lie between 3-14 days in order to produce a biological floc which can be handled easily. For  $\theta_c$  less than 3 days, the biomass is not dense enough to settle easily, producing "bulking sludge." For  $\theta_c$  greater than 14 days, the floc particles are too small to settle rapidly and the fraction of living cells in the biomass is low. Good sludge settling properties are essential for an efficient gravity settler operation and a stable activated sludge process. Since the sludge age largely governs how well a floc will settle, an age value is chosen based upon experience and the type of sludge generated in the process.

The sludge age can be controlled by the wastage rate from the bottom of the settler or by the rate of sludge recycle. By decreasing the sludge wastage rate, the sludge age is increased. The same result can be obtained when the rate of recycle ratio (R) is increased. (Donald and Herbert, 1979). Perdrieux et al. (1980) showed that higher sludge age results in better assimilation of the substrate by the cell and increases the rate of utilization of the stored carbon for energetic requirements.

### Effect of Recycle Ratio

The purpose of the recycle of sludge is to maintain a sufficient concentration of activated sludge and to increase the concentration of the biomass in the aeration basin. The addition of a recycle stream dilutes the concentration of entering substrate and decreases the residence time of fluid elements in the aeration basin. So the required degree of treatment can be obtained in the time interval desired. The return of activated sludge from the clarifier to the inlet of the aeration tank is the essential feature of the process.

Recycle ratio (R) is defined as the ratio between the recycle flow rate to the aeration tank and influent flow rate. Figure 2 shows the effect of change of recycle ratio on the percentage removal efficiency of the substrate and ammonia at certain conditions of  $S_r$ ,  $H_r$ ,  $C_r$  and (P/V). As R increases removal efficiency of substrate increases till it reaches 84% at R = 40%, then it reaches 86% at R = 80 %. Finally, it becomes almost constant with further increase of R where it appears that substrate removal efficiency is not enhanced by a recycle ratio larger than 80%.

With respect to the ammonia, the percentage removal efficiency increases from 33.991 at a very small value of  $R$  till it reaches 52% at  $R$  equals 80 %, then becomes constant as  $R$  increases. It appears that ammonia removal efficiency was not enhanced by a recycle ratio larger than 80%. In the first stage, when  $R$  increases in the range 0-80% the removal efficiency of substrate and ammonia increases continuously. The rate of biomass production increases dependently, and the produced biomass degrades the organic substrate (BOD) and ammonia efficiently. This explains why percentage removal efficiency increases till it reaches nearly 80%. However, in the second stage, the percentage removal efficiency becomes constant because the aeration is unable to supply the excess biomass to the necessary oxygen in addition to the rate of increasing biomass concentration will be reduced as  $R$  increases as shown in Fig. 3. When the operating conditions change, the curves in Fig. 2 will have the same shape, but they are shifted to the right or the left according to the available conditions. Figure 3 shows that the effluent biomass concentration ( $X_{out}$ ) will always increase as  $R$  increases due to the biomass resulting from the degradation of the substrate and ammonia. Yuichi et al. (1992) showed that the higher the concentration of sludge biomass in an aeration basin, the larger the number of microorganisms and the number of flocs that possess aerobic and anoxic micro-sites inside the flocs. Thus the oxidation and denitrification rate in the aeration basin will be enhanced by higher volumetric BOD loading. Since organic matter is essential for oxidation and denitrification, Tashiro et al. (1990) showed that it might be difficult to carry out simultaneous carbon-nitrogen removal when the influent is applied to this process.

Since the sludge age largely governs how well a floc will settle, it is important to study the effect of recycle ratio on sludge age. Figure 4 shows the effect of change of  $R$  on the sludge age,  $\theta_c$ , in the aeration tank. It is shown that  $\theta_c$  increases continuously as  $R$  increases. It is noted that the increasing of  $R$  will increase the biomass concentration, and consequently a better assimilation of the substrate by the cell can be obtained and the rate of utilization of the substrate for energetic requirements can be increased (Perdrieux et al., 1980). Hence, the sludge age can be controlled by the sludge recycle from the bottom of the clarifier.

### Effect of Influent Flow Rate

It is important to study the effect of influent flow rate, as an external factor, on the percentage removal efficiency because it is very difficult to control. Logically, the increasing of flow rate will cause high loading on the performance of the plant. Figure 5 shows the effect of increasing the flow rate on the removal efficiency of substrate and ammonia. It is shown that the removal efficiency of substrate decreased from 100% at very small values of the flow rate to 36.5% at  $Q=100,000 \text{ m}^3/\text{d}$ . The same is true for ammonia, but the removal efficiency of ammonia is less than that of substrate.

Figure 6 shows that  $X_{out}$  increases from 25mg/l till the highest value of 4577 mg/l at 50,000  $\text{m}^3/\text{d}$  then decreases as the flow rate increases till reaches the constant value. The highest value of  $X_{out}$  can be considered the optimum value, and the flow rate then is called the critical flow rate. The microorganisms after the critical flow rate are washed out of the reactor faster than they are generated by the reaction under washout conditions.



The concentration of biomass in the reactor decreases and the conversion of substrate decreases.

In fact, optimizing the different flow rates in the plant is an interesting area of research. Real wastewater treatment plants should work in a range of flow rate close to the critical to fulfill the highest effluent biomass such as Helwan WWTP which has a flow rate of 43750 m<sup>3</sup>/d. Maintaining a high concentration of biomass is a tempting strategy to improve plant performance since a large biomass can degrade more organic material. However, other forms of microorganisms may adapt to the high concentration of biomass, which in turn makes the activated sludge process less efficient. These results agree with Muller et al. (1995) who showed that a very low biomass production could be achieved when a very high influent flow rate is applied.

Figure 7 shows that the increasing of flow rate will decrease the sludge age in the reactor; hence the removal efficiency of the aeration basin decreases. The microorganisms will not have enough time to oxidize the substrates and ammonia and it is required to control the influent flow rate to maintain a high conversion. The sludge age can be calculated at the critical flow rate according to Eq. (14), and equals 8.6 days. This is an optimum value for the sludge age that allows sufficient time to perform different biodegradations

### Effect of Influent Substrate Concentration

The influent composition is important for the design and control of a WWTP. The concentration of influent substrate determines the performance of the plant. Benefield and Randall (1985) showed that although substrate treatment would not likely be affected until a very low concentration was reached, a distinction between excess and low concentration was made since nitrification is limited at concentration less than 2 mg/l.

In Fig. 8, the behavior of percentage removal efficiency can be classified into two stages. In the first, the conversion of substrate increases with increasing  $S_f$  from 77.7 % at small values of  $S_f$  to reach 96.5% at  $S_f = 700$  mg/l; then it becomes constant as  $S_f$  increases. This means that the output substrate concentration remains constant, but in the second stage the effluent substrate concentration remains constant and does not depend upon the entering substrate concentration. It appears that the removal efficiency was not enhanced by  $S_f$  larger than 700 mg/l. This response represents an inherent "self control" by the reactor since changes in feed concentration do not affect the output substrate concentration (Donald et al., 1979). This can be understood by Fig. 9 where the effluent biomass (biological solids) concentration is increasing linearly as  $S_f$  increases sufficiently to handle the higher loading of the substrate. The percentage removal efficiency of ammonia increases from 44.3% at a very small value of  $S_f$  then increases continuously till it reaches 86.6% at  $S_f = 1409$  mg/l.



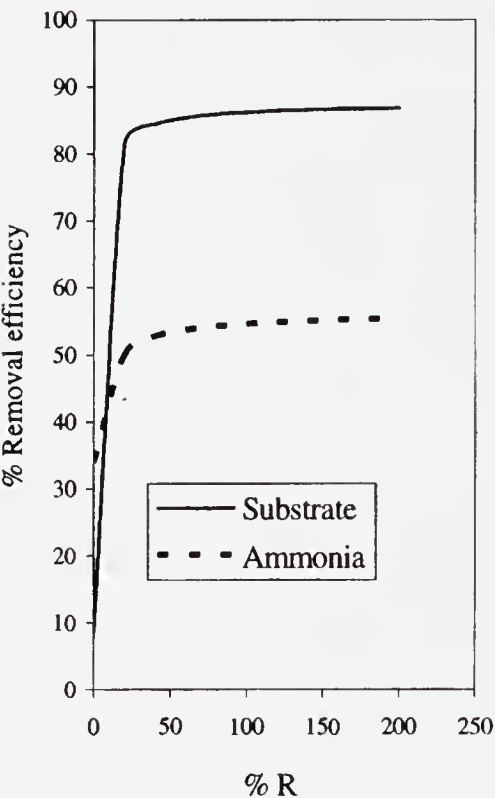


Figure 2. Effect of recycle ratio on removal efficiency.

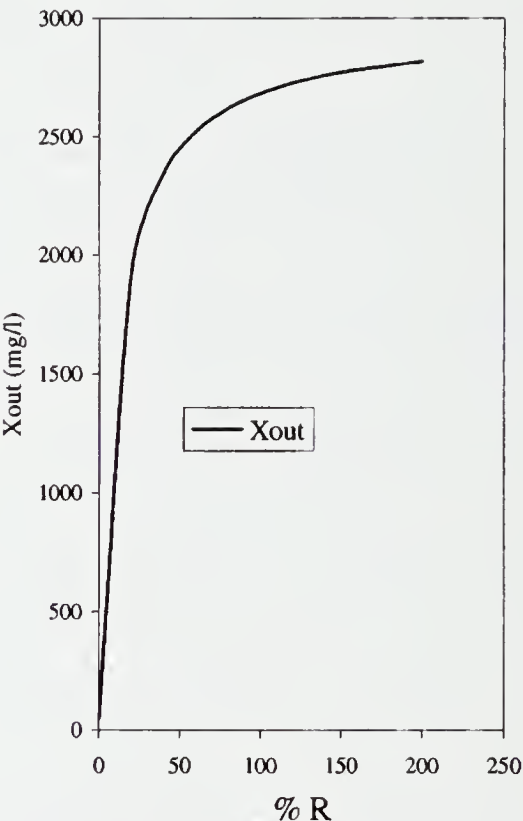


Figure 3. Effect of recycle ratio on biomass effluent.

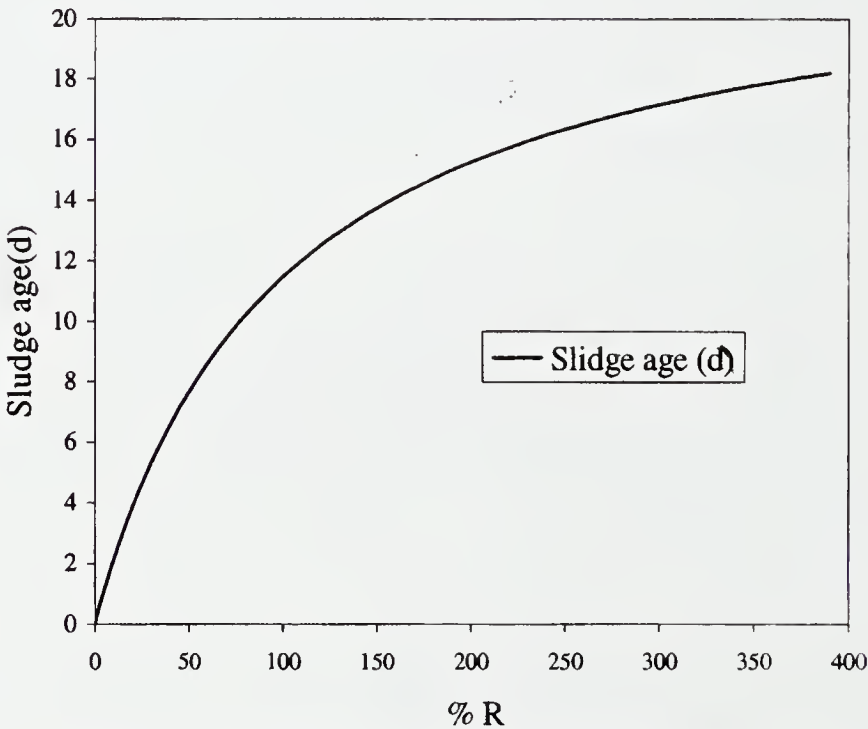


Figure 4. Effect of recycle ratio on sludge age.

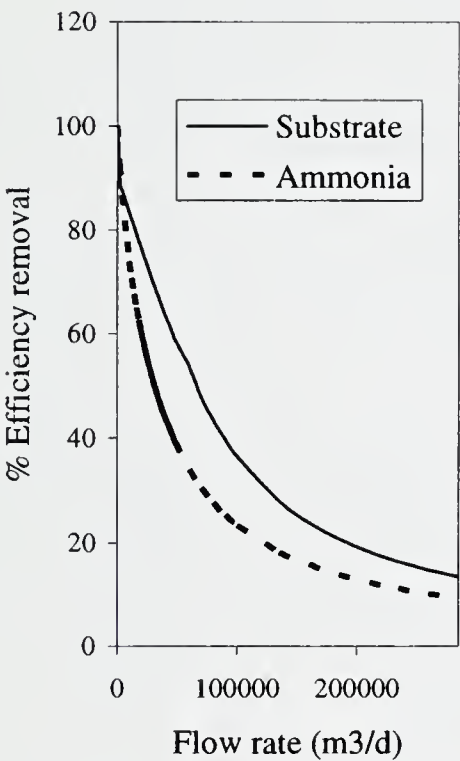


Figure 5. Effect of flow rate on removal efficiency.

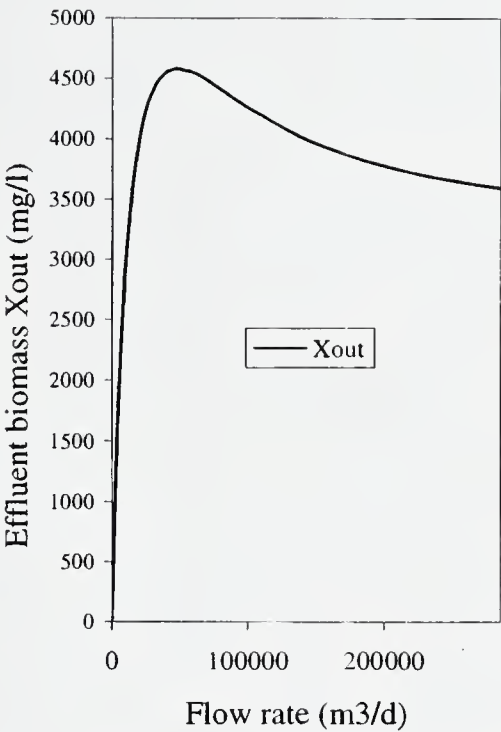


Figure 6. Effect of flow rate on effluent biomass.

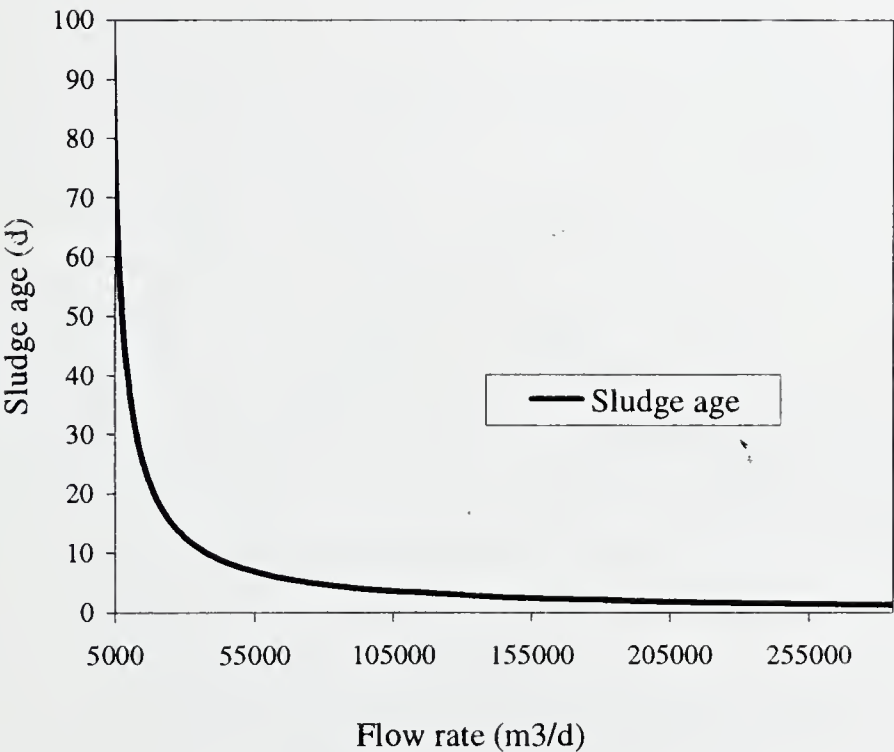
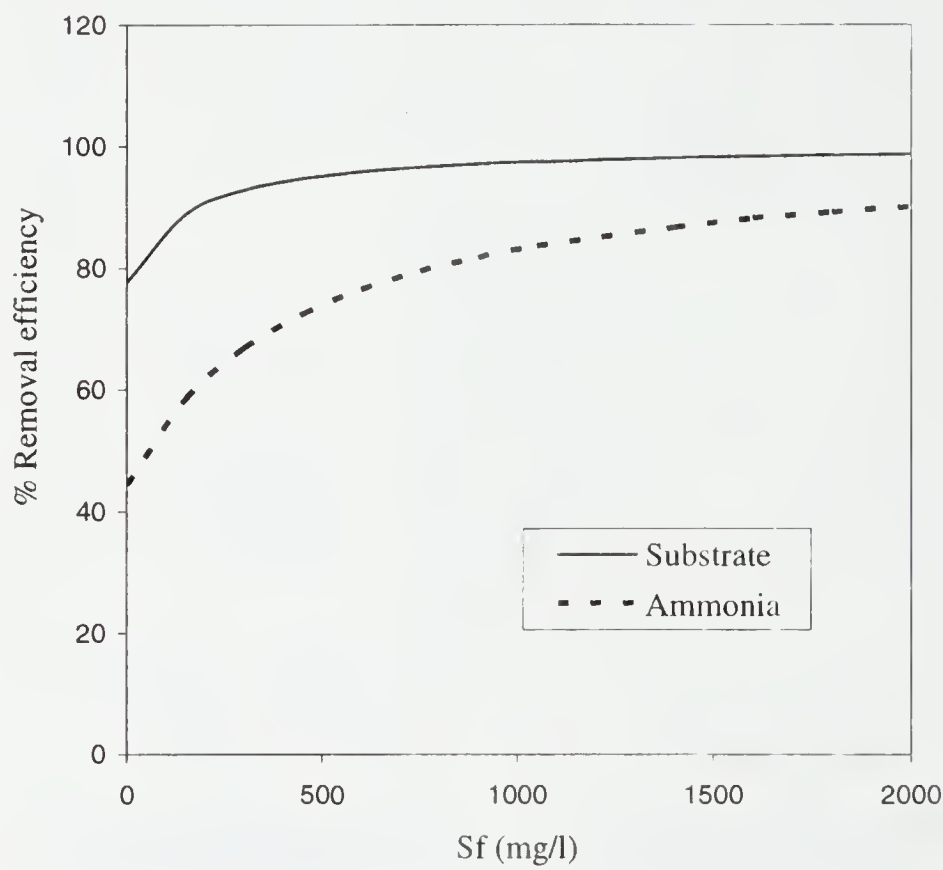
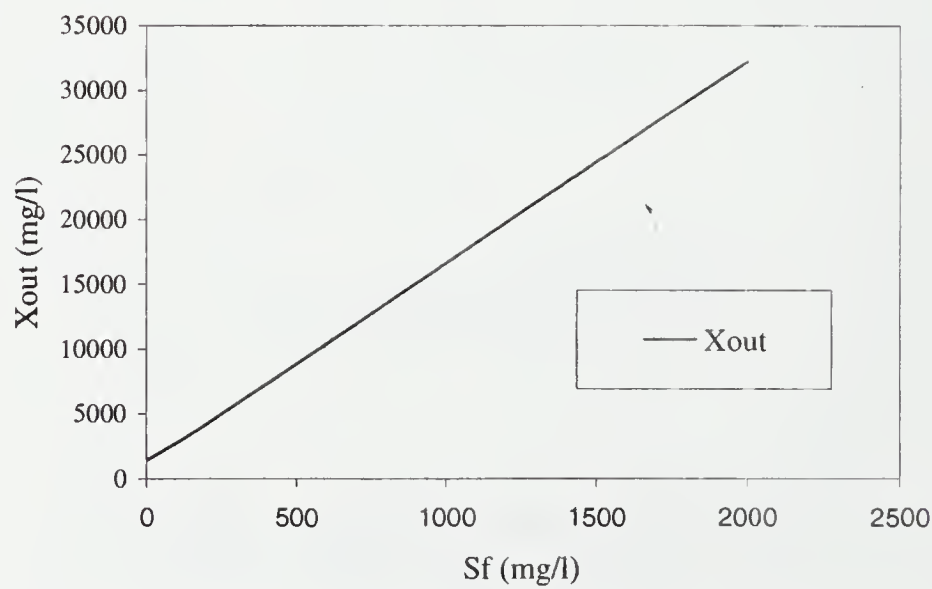


Figure 7. Effect of flow rate on sludge age.



**Figure 8.** Effect of feed substrate concentrations on % removal efficiency.



**Figure 9.** Effect of feed substrate concentrations on effluent biomass ( $X_{out}$ ).

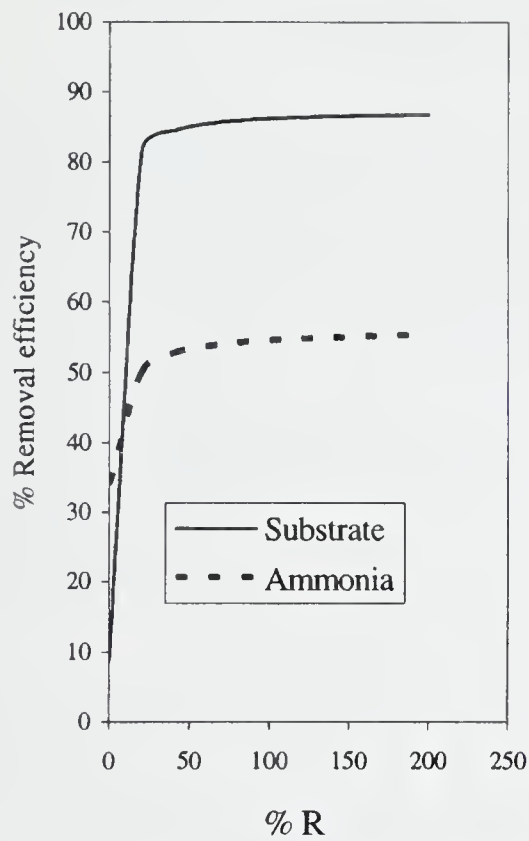


Figure 2. Effect of recycle ratio on removal efficiency.

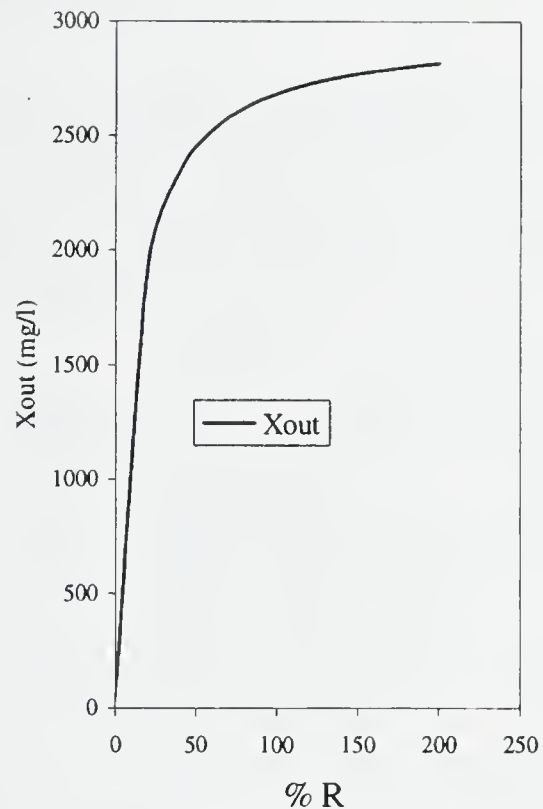


Figure 3. Effect of recycle ratio on biomass effluent.

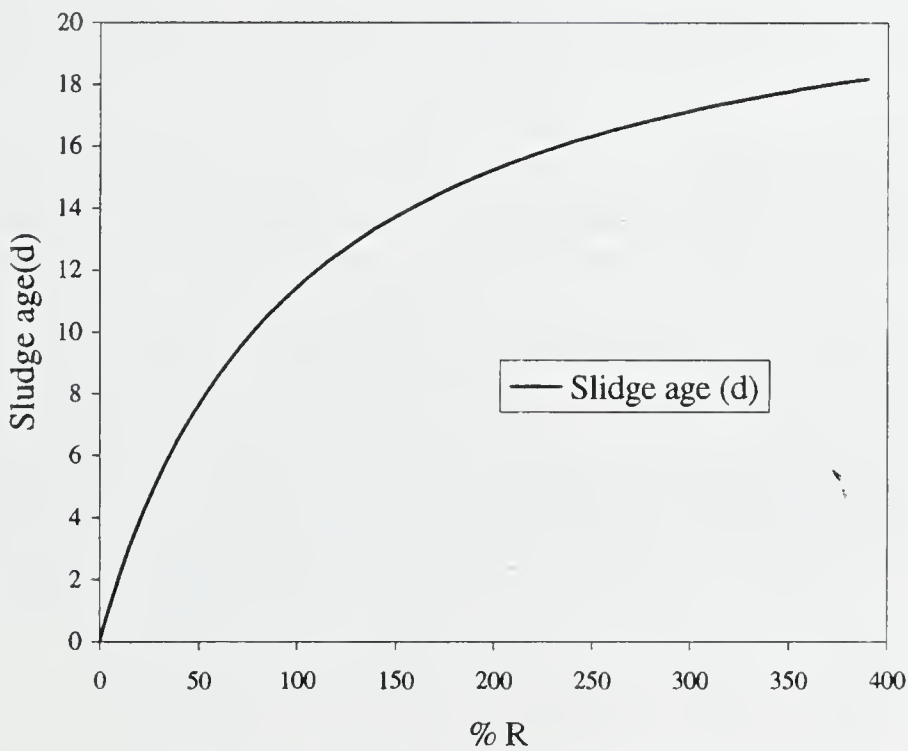


Figure 4. Effect of recycle ratio on sludge age.



## CONCLUSION

A mathematical process model was developed for the aeration tank of the activated sludge plant. Identification of kinetic and stoichiometric parameters was studied in order to obtain the suitable values of parameters as shown in Table (2) to prepare the model for the simulation purpose and to obtain results compatible with true activated sludge plants. It was found that some parameter values such as half saturation coefficients were found out of the range of ASM1 (Henze et al. 1987) due to the mass transfer limitations in the floc model. Some other parameter values such as the ammonia stripping factor were assumed. The other parameters such as saturated concentration of oxygen were taken from ranges given in the literature. In this study, two Egyptian wastewater treatment plants were used: Helwan WWTP and Zenine WWTP. The two plants are different in some conditions such as aeration tank volume, flow rates, and the aeration technique. Helwan WWTP uses the surface aeration with mechanical agitation technique while Zenine WWTP uses the diffused air technique.

Helwan WWTP data were used through the simulation of the response of different components of substrate (BOD) and ammonia. Zenine WWTP was used for testing and validation of the process model through the prediction of the substrate only. The average errors of the removal efficiency of the actual results of the plant and the theoretical results of the process model were measured. The average error of the removal efficiency in Helwan WWTP reached 3.311 % for the substrate and 12.521 % for the ammonia. However, in Zenine WWTP it reached 4.634 % for the substrate. These results emphasize the model validation and the kinetic parameter accuracy.

A parametric study of the activated sludge was performed. The effects of recycle ratio, flow rate, and influent substrate concentrations on the removal efficiency of the aeration tank were studied. It has been found that the removal efficiency of substrate and ammonia was increased by increasing the recycle ratio and influent substrate concentrations and also increased by decreasing the influent flow rates. It has found that the sludge age increased by increasing the recycle ratio and decreased by decreasing the influent flow rates. The highest value of  $X_{out}$  can be considered the optimum value, and the flow rate then is called the critical flow rate. After the critical flow rate is reached, the microorganisms are washed out of the reactor faster than they are generated by the reaction, so the concentration of biomass in the reactor decreases and the conversion of substrate also decreases. The sludge age is calculated at the critical flow rate according to Eq. (15) and equals 8.6 days; this value allows sufficient time to perform different biodegradations. Maintaining a high concentration of biomass is a tempting strategy to improve plant performance since a large biomass can degrade more organic material. However, other forms of microorganisms may adapt to the high concentration of biomass, which in turn makes the activated sludge process less efficient.

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## SCIENCE AND THE UNDERSTANDING OF CONSCIOUSNESS

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The study of consciousness has come alive in the past several decades. Researchers are drawn to the area and energized by the belief that they now have the skills and technology to address a problem that has bedeviled humanity for centuries (Koch, 2004, p. 314). Christof Koch formulates the hope nicely. He says, "Science seeks a causal chain of events that leads from neural activity to subjective percept; a theory that accounts for what organisms under what conditions generate subjective feelings, what purposes they serve, and how they came about" (Koch, 2004, p. 326).

Despite this optimism, several commentators assert Koch's goal can never be achieved. One of them, Stevan Harnad, makes the skeptics' case vividly. He employs an example of free floating anxiety, a conscious state that has arisen without any discernable cause and serves no apparent purpose. He then notes the relations between brain states and the state of anxiety that science can trace:

So suppose we find its correlates, the pattern of brain activity that occurs whenever we feel anxious. And suppose we go on to confirm that that brain activity is not only correlated with anxiety, but it causes it in that (1) it comes before the feeling, (2) if it is present we feel anxiety, (3) if it is absent we do not, and (4) there is no other correlate or cause that we have missed, and (5) we can explain what causes that pattern of brain activity. (Harnad, 2005, p. 56)

Harnad is convinced that these correlations, though they indisputably reveal causal relations, will never yield a complete understanding of the relation between brain states and states of consciousness. He asks, "Now, what about the 'how'? How does a pattern of brain activity generate feeling? . . . It is a question about how feeling itself is generated" (Harnad, 2005, p. 56; see also, Chalmers, 1995, p. 201 and p. 207). Harnad appears to agree that science can achieve Koch's goal of tracing a causal chain of events leading from brain states to states of consciousness. However, he denies this success will open the way to Koch's goal of constructing a theory competent to explain this relationship.

In the brief letter quoted above, Harnad provides no evidence for his assertion, nor does he explain why he is convinced that science can never devise a theory to fully explain the relation between brain states and states of mind. The difficulty he finds can be characterized in at least three ways. Each will be examined in turn.



## CAUSAL INCOMPLETENESS

Though he seems to agree that science will eventually trace a causal chain which connects brain events to states of mind, it is possible Harnad believes that science will never uncover the complete array of causal steps that connect brain states to states of consciousness. Perhaps he is convinced that the causal chain unearthed by scientific investigation can never be sufficiently detailed to allow a satisfactory theory of the relation between brain states and states of mind. Or, Harnad may believe that some essential links in the causal chain must always lie beyond the reach of science.

These are important concerns. If the causal chain available to science must necessarily remain overly coarse or incomplete, researchers will not be able to devise a theory competent to explain the relation between brain states and states of mind. However, it appears that lack of sufficient causal detail poses no difficulty for science. For decades researchers have been able to record the activity of individual neurons (Kandel, 2000, et al., pp. 176--86; Koch, 2004, pp. 28--33; For an intriguing examination of the role of individual neurons in memory, see Quiroga, et al., 2005). There is no reason to believe that science requires finer resolution than is provided by the ability to monitor single neurons. In addition, recent technological advances, including positron emission tomography (PET) and Functional Magnetic Resonance Imaging (fMRI), allow researchers to examine the function of whole living brains (Blackmore, 2004, pp. 228--9). Christof Koch does not yearn for technology with higher resolution than is presently available. Rather, Koch believes that the challenge for research resides in a domain intermediate between single neuron firing and whole brain activity. He hopes for technology to observe tens or hundreds of thousands of neurons at work (Koch, 2004, p. 312 and p. 323). Perhaps such technology will always lie outside the reach of science, but there is presently no reason to believe this must be the case. As a result, there is little reason to accept the conclusion that the causal chain accessible to science must remain too coarse to allow complete understanding of the relation between brain states and states of mind.

Nonetheless, it remains possible that critically important links in the causal chain must always lurk beyond human reach. The difficulty can be stated as follows: Science can observe chains of physical events in the brain. Under proper conditions, these chains of physical events will result in states of mind. States of mind are presumed to be nonphysical. But, nonphysical states cannot be directly observed by science. Their existence can only be inferred from external observation. Hence, there must be a point at which direct observation halts and the inference of mental activity begins. Since the point at which brain states activate states of mind can never be observed, it may seem reasonable to infer that science can never construct a successful theory to explain the relation between the physical and the mental.

However, if lack of direct observation of mental phenomena is the difficulty, it hardly seems insurmountable. In fact, it is no difficulty at all. Much of the fundamental science of the 20<sup>th</sup> Century is built on inferences from what can be directly observed to that which cannot be. Subatomic physics is an instructive example. Neutrinos, quarks,



pi mesons, and the like will perhaps never be monitored directly. The link between the observable and the unobservable is provided by theories that allow researchers to infer the relations between directly observed phenomena and unobservable particles. Hence, in the domain of subatomic physics, the link between the directly and indirectly observable is provided by theory. Obviously, successful theories of subatomic physics have been formulated even though they connect the observable to the unobservable

Of course, there may be other reasons why it may be impossible to devise a satisfactory theory of the emergence of states of consciousness from brain states. This possibility opens the way to a second difficulty Harnad may have in mind. It is a problem which has been vigorously formulated by the philosopher David Chalmers.

## CONSCIOUS STATES ARE SIMPLE

Chalmers has devoted considerable energy to developing the position that studying brain states can never yield the understanding necessary to explain the existence of states of consciousness. He insists, "The structure and dynamics of physical processes yield only more structure and dynamics, so structures and functions are all we can expect these processes to explain. The facts about experience cannot be an automatic consequence of any physical account, as it is conceptually coherent that any given process could exist without experience. Experience may arise from the physical, but it is not entailed by the physical" (Chalmers, 1995, p. 208).

There is a quick and easy response to Chalmers' claims, and a longer, more complex rejoinder. Koch has the quick and easy response (Koch, 2004, p. 6). He agrees that we presently have no concepts able to link physical states to mental experiences. Therefore, Chalmers and others are quite right to insist that conceptual analysis will not reveal a connection between brain states and states of consciousness. But Koch is convinced that this does not mean we can never devise such theories. Doing so is the goal of his research. He forthrightly acknowledges that his efforts may fail, but he finds no reason to believe they must fail (Koch, 2004, p. 6 and p. 326). For much of human history, we have understood that adding sufficient heat to liquid water will produce steam. However, we had no proven theory able explain this relationship. Our discovery of the molecular composition of water and the effects of adding energy to that molecular structure allowed complete understanding of the process that leads from liquid water to steam. In similar fashion, the recognition that changes in brain states may cause changes of consciousness is comparatively recent. Nonetheless, we presently have no reason to conclude that a theory that will explain the connection must remain permanently beyond our reach.

Chalmers, however, believes his argument should be viewed in a different way, and that version requires a more complex response. He asserts that the relationship of liquid water to steam is not analogous to that of the relationship of brain states to states of consciousness because water and steam are both physical. Brain states and states of consciousness differ because states of consciousness are not physical (Chalmers, 1995, pp. 8--9). At first glance, it is not obvious that this distinction should matter. Though

both physical, liquid water and steam have distinct properties. Also, though living and nonliving beings are quite different, educated people are at ease with the train of steps which lead from nonliving matter to life forms (Fry, 2000, pp. 1--8 and pp. 65--78).

Chalmers nonetheless insists there is a critically important difference between the cases. Physical things can be analyzed into their elemental constituents, and we can understand how these physical constituents are reconfigured when physical stuff changes from one state to another. For example, we are aware that both liquid water and steam are composed of water molecules, but the molecules have different energy levels in the two states. In the case of nonliving matter and live organisms, Chalmers points out that we have determined that life consists of a series of functions, i.e., metabolism, reproduction, etc., and we can understand how the assemblage of these functions can be performed by nonliving matter (Chalmers, 1995, p. 204 and p. 208).

In contrast, our ordinary experience of conscious states prompts us to believe they are not functions and have no structure. They are completely simple, in other words. Hence, they cannot be analyzed into more elemental states. Even if they could be thus dissected, it is possible that any simpler constituents will also be immaterial entities. Furthermore, as the example of free floating anxiety illustrates, it appears that states of consciousness cannot be resolved into an array of functions. Apparently, Chalmers believes we give complete explanations of states of consciousness in terms of physical brain states only by analyzing them into simpler constituents and observing their interaction or by dividing them into an array of functions. In consequence, he believes we will never be able to fully explain the relation between physical states and states of consciousness (Chalmers, 1995, pp. 8--9).

If the above reading is correct, Chalmers' position has shifted. The sticking point is no longer the perceived difference between states of matter and states of mind. Rather, the difficulty is that we experience states of consciousness as simple. Though they may have functions, they are not functions. They appear to have no structure which could be analyzed. Consequently, we will never understand states of consciousness completely in terms of physical constituents. But, if that is the sticking point, the situation is not as hopeless as Chalmers believes.

As always, researchers remind us that introspection has often proven an unreliable guide to neurological research (Koch, 2004, p. 316). It is entirely possible that our conception of states of consciousness will change as neurological research progresses. After all, advances in other areas, such as physics, have been accompanied by significant changes in conceptions of space, time, mass, motion, etc. Thomas Nagel believes that the ultimate solution to the problem of the relations between minds and brains must await a revised and deepened conception of consciousness (Nagel, 1998, pp. 337--8). Recent neurological research offers a hint of how this revision may occur. It reveals that even the simplest visual experience is the product of an astonishing array of different neural processes that are parceled out to distinct parts of the brain and occur at varying speeds (Kandel, et al, 2000, pp. 496--500). Hence, one sector of the brain responds to edges, another to colors, another to shape, yet another to contrasts of light and dark. Somehow,

these strands of neural processing are then united to produce our (apparently) unitary visual experience. The question of how these strands merge into unified experience remains unanswered and is termed the “binding problem” (Kandel, et al, 2000, p. 502; Koch, 2004, p. 43, pp. 167--70 and Blackmore, 2004, pp. 244--8). Hence, contemporary research reveals that our conscious states are not simple even though we experience them as such<sup>1</sup>.

It is entirely possible, though in no way assured, that scientific research will at some point determine how to divide experience into its constituents. These constituents may or may not display consciousness awareness. If they do, it is possible researchers will determine how they arise from nonconscious states. If they do not, researchers may determine how consciousness arises from their combination. At present, we are unable to deny that these are possible outcomes.

Nonetheless, Chalmers could well remain unmoved by such advances. He might claim that we are either conscious or not. It doesn't matter that experience is formed from a variety of constituents, and it doesn't matter that these constituents are somehow bound together. The point is that, once conscious awareness is achieved, it is achieved wholly. Even if the experienced content of consciousness is formed from an array of elements, our conscious awareness either exists or does not. When it exists, it is experienced as simple.

This is a significant point. But, again, the matter is not as simple as everyday experience seems to indicate. Hospital emergency room workers and anesthesiologists are well aware that there are different types of consciousness and that each is present to varying degrees. Conscious awareness is not simply present or absent. Further, no sharp boundary separates conscious from unconscious states. In some cases, there is no clear agreement on whether a state should be considered conscious or not (Nikolinakos, 1994, pp. 93-100).

It is possible Chalmers will be undeterred by this complexity as well. He may well insist that, when consciousness is clearly present, it is simple. It doesn't matter that we on occasion have difficulty determining whether a particular state is a state of consciousness, and it doesn't matter that consciousness is present in degrees. The important point is that conscious states are simple and unanalyzable when present.

But, once again, Chalmers' argument butts up against researchers' observations that introspection has proven a poor guide to the understanding of consciousness. Though our states of consciousness appear simple, it remains possible that they are not. Chalmers may respond that by definition consciousness is what we experience. Hence, it is impossible for us to be mistaken about it. This is a compelling argument. Unfortunately, it is mistaken. As noted earlier, research demonstrates that though experience appears to us to be unitary, it is in fact not so. The very simple visual perception of a coffee cup requires the processing of information about color, boundary, shape, texture, and location. Information about these matters is processed in different domains of the brain, and the processing occurs at different rates. Researchers are presently at a loss to explain how we experience these things as unitary. Another line of research has shown that blind people commonly use echolocation to navigate. However, they describe the experience as feeling pressure on their faces rather than as an auditory response (Schwitzgebel and Gordon, 2000).



Nonetheless, let us suppose Chalmers' claim that experience is simple and unitary is correct. Would this demonstrate that no theory can be devised to explain how states of mind arise from states of matter? This is a plausible claim, but is it correct? Given his remarks, it appears that Chalmers is most concerned to refute reductionism, the view that mental states can be analyzed into physical brain processes. However, if this is Chalmers' concern, there is little reason to believe that researchers in the area, such as Koch, would disagree. The question, then, is, "If conscious states are unanalyzable, is it impossible to explain them in terms of the activity of brain states?" Apparently, Chalmers believes this to be the case. He is convinced that researchers can, at best, concoct "bridge principles" which will correlate states of consciousness to brain states (Chalmers, 1995, p. 10).

However, the ultimate constituents of the universe such as electrons, photons, quarks, etc. are also simple in the way Chalmers believes consciousness to be. That is, they are without internal structure and are not functions (Greene, 1999, p. 124)<sup>2</sup>. Nonetheless, under proper circumstances, photons, the elemental units of electromagnetic force, can become electrons, elemental units of matter, and electrons may become photons (Greene, 1999, pp. 158--60). What is more, science has an elegant and profound explanation of these transformations, Einstein's formulation of the equivalence of matter and energy (Greene, 1999, pp. 51--2 and p. 120). Thus, in the physical sciences it is possible to provide explanations of the ways in which simple entities can be created, transformed, and destroyed. As a result, it is apparent that the simplicity of states of consciousness does not debar a convincing explanation of their relationship to brain states.

At this point, scientists such as Koch seek only to trace out the complete story of the causal connections between states of consciousness and brain states. Harnad is entirely correct to insist that examining this causal chain will not automatically yield a theory of the relation between brain states and states of consciousness. But, as in all other fundamental theories, from Copernicus' theory of planetary motion to Bohr's quantum mechanics, successful theory is not simply read from the data. Rather, it must result from human thought and insight. These tasks may prove simpler if, as Nagel believes, future research prompts us to revise our conception of consciousness. As always, there is no guarantee that examination of the causal chain will yield a viable theory, but the possibility cannot be ruled out simply by claiming that states of consciousness are completely simple.

### **THIRD PERSON ACCOUNTS OF FIRST PERSON EXPERIENCE**

A third possibility is that Harnad is convinced science will never be able to devise a successful third-person account of our first-hand experience of conscious awareness<sup>3</sup>. In an earlier exchange, Harnad comments, "In the special case of mind we are instead trying to replace SUBJECTIVITY ITSELF by something OTHER than subjectivity, appearances by something other than appearances" (Harnad, 1993, p. 15). It appears that Harnad believes that a successful theory of consciousness must somehow capture the essence of subjectivity. However, according to one philosopher consciousness is completely transparent (Moore, 1903, p. 450)<sup>4</sup>. The state of consciousness is invisible even to the conscious subject. Thus,



to grasp a conscious subject's experience, researchers must aim to fathom the contents of conscious states. That is, they, as external observers, must understand exactly what a conscious experimental subject feels. Of course, it is unclear how this might be achieved. As it happens, several authors have formulated this challenge to scientific inquiry in detail.

Thomas Nagel has recently asserted that the ultimate goal of a scientific theory of consciousness is to give genuine content to the statement, "That's what the experience of tasting chocolate looks like from the outside" (Nagel, 1998, p. 337). This opens the possibility that science will allow us to determine the precise array of sensations a research subject is experiencing simply by scanning monitors of physical brain activity<sup>5</sup>. It appears that science can meet Nagel's challenge without particular difficulty.

It seems likely that science will at some point be able to precisely determine which arrays of neurons become active whenever we have a particular sensation, and it will also be able to precisely correlate that neural activity with the different elements of an experience that we perceive as unitary. In addition, science may acquire the ability to accurately predict the exact constituents of our sensations when particular neural networks become active. At that point, science would indeed have the means to reveal to Professor Nagel exactly how chocolate tastes from the outside. It could, in other words, present him with the entire array of sensations he would have were he tasting chocolate.

As it happens, a beautiful bit of science gives an example of how this effort might proceed. "What the frog's eye tells the frog's brain," first published in 1959, records the types of information a frog's retinal neurons convey to its brain. The researchers conclude, "The output from the retina of the frog is a set of four distributed operations of the visual image. These operations are independent of the level of general illumination and express the image in terms of 1) local sharp edges and contrast, 2) the curvature of edge of a dark object, 3) the movement of edges, and 4) the local dimmings produced by movement or rapid general darkening" (Lettvin, et al., 1959, p. 1950). The authors are pleased to label this array a "bug detector" (Lettvin, et al., 1959, p. 1951). It is reasonable to believe that scientists may eventually be able to map the output of each type of frog neuron, determine what each registers, and discover the ways in which these signals combine in the frog's experience. Should that be achieved, it seems entirely sensible to claim we would be able to fathom the entire content of a frog's consciousness at any instant<sup>6</sup>. In that event, scientists would have met Nagel's challenge of grasping the contents of a particular conscious state from the outside, at least with regard to the frog, if not with the taste of chocolate.

It is probable that Harnad will be dissatisfied with this idea and may express his dissatisfaction in two ways. First, he is likely to note that these studies will be based on correlations only, so they cannot meet the challenge he posed initially. However, if the challenge is understood as the challenge of describing the essence of subjectivity, and if that is understood in turn as understanding the contents of someone's consciousness from the outside, then Harnad's dissatisfaction is beside the point. If his challenge has been correctly formulated above, then it has been met.

However, Harnad's dissatisfaction may take a different and more probing form.

He may well note that, when Lettvin, et al., 1959, move convex shapes across a screen and record that certain frog neurons fire, the human researchers are recording what they experience. Human eyes perceive the movement of convex shapes, but the frog may experience something entirely different. The researchers have no way to determine exactly what the frog experiences. That is a limitation of relying on causal correlations only.

This difficulty is important, but it is not insurmountable. Scientists have long understood that analogy is a powerful instrument for extending human knowledge. After all, the foundation of any individual's belief that his or her fellow human beings possess conscious experience is the conviction that they are relevantly like him or her. Hence, to determine whether the frog's experience is similar to ours, researchers would have to determine whether frog neurons devoted to visual perception and their neural circuits resemble ours. If they differ, researchers could examine the ways in which they differ, attempt to determine whether they are likely to alter the frog's perceptual experience, and, if so, what the difference is likely to be. On the assumption that similar structures retain similar functions across evolution, researchers would have considerable justification for presuming the resulting experience was similar. Certainly, there would be little evidence to support a conclusion that the frog's experience differed.

A different line of argument yields a similar conclusion. It is reasonable to presume that there is a significant evolutionary advantage in perceiving the world as it genuinely is. There are objective measures for shape, contrast of light and dark, etc, so it is likely these are aspects of the world as it is. Hence, there is support for the conclusion that both humans and frogs experience the world as it is. However, Lettvin, et al., 1959, also have good reason to believe that the frog's experience is quite distinct from our own in certain ways. The evidence of their research supports the view that the frog experiences only several abstracted features of moving insects and not the complete array of features we are able to experience. So, neural research is able to reveal the ways in which our experience and that of frogs are alike and ways in which they differ.

But, frogs are not human beings, and human conscious states are vastly more complex than those of frogs<sup>7</sup>. We can ask whether it may be possible to canvass the conscious states of human beings. There is evidence to support the hope that such a prospect exists. At present, researchers can determine which single neurons hold the memory of a particular face (Quiroga, et al., 2005). At some point, they may very possibly be able to determine exactly how individual memories are encoded in single neurons and how networks of neurons work to retain the memory. Once this information is in hand, not merely for individual faces but for all memories and the entire array of sensations an individual is experiencing from instant to instant, researchers should be well equipped to determine the contents of an individual's thoughts from the outside—assuming appropriate detection apparatus is available. It will obviously be extremely difficult to gain all this information, and the effort may require many decades, but there is presently no reason to believe it will never be achieved. In consequence, it appears that there are ample resources for assuaging Harnad's dissatisfaction.

This is not the end of the difficulty posed by subjectivity. Some years ago, Nagel



issued a more probing challenge. In his famous article “What Is It Like to Be A Bat?,” Nagel argued that no matter how much knowledge of a bat’s brain we amass, we will never be able to understand the kinds of experiences the bat has in the way it has them—assuming it has phenomenal consciousness rather than bare access consciousness. “I have said that the essence of the belief that bats have experience is that there is something that it is like to be a bat.... But bat sonar, though clearly a form of perception, is not similar in its operation to any sense that we possess, and there is no reason to suppose that it is subjectively like anything we can experience or imagine” [emphasis added] (Nagel, 1979, p. 168). In this formulation, Nagel’s concern is that we can never come to scientific terms with conscious states that we have reason to believe are highly dissimilar to any we personally have experienced. The critically important point is that he believes that the experience of the bat is so radically different from ours that we are unable employ the tool of analogy to examine it.

Philosopher Frank Jackson in “What Mary Didn’t Know” concocts an argument akin to Nagel’s early challenge. Jackson is not immediately concerned with the relation of brain states to conscious states. Rather, he is eager to demonstrate that the universe is not composed of physical stuff only. He constructs a science fiction scenario in which a scientist, Mary, matures and is educated in an enclosed space without experience of colors other than black and white<sup>8</sup>. Jackson postulates that she could master all available scientific information regarding the nature of color and color vision. However, he is convinced that, if she were then exposed to a color, such as red, she would agree that she had learned something novel, namely, what the sensation of redness is like. Jackson asserts she could never have learned this from studying the scientific literature of the physical nature of colors and the processes of color vision. He is satisfied this demonstrates that the examination of physical stuff cannot reveal the entirety of what exists—assuming that science can examine physical stuff only (Jackson, 1982). Jackson’s position is obviously relevant to the endeavors of consciousness researchers. No matter how thoroughly scientists delineate the structure and function of neural cells, Jackson believes their studies will never reveal what experience is genuinely like.

For the sake of clarity, it is worth pausing to note that Nagel and Jackson do not claim that a successful theory of consciousness must give us the sensations associated with the experience of the color red. This can be ruled out quickly, since no theory could achieve that. Jackson does not wish his claims to be construed in this way, since he allows that Mary, on being exposed to the color red, may respond, “Aha, that’s what I thought it would be like”—apparently based on her scientific studies (Jackson, 1986, p 291). Jackson believes she will not give this report but instead will say, “So, that’s what red is like.” So, he is claiming that a successful theory must allow us to determine exactly what Mary’s sensation of red would be like, though it would not create that sensation in us. And, of course, it is difficult to imagine how a theory could accomplish this.

Taken together, Nagel and Jackson are asserting there are at least two domains of consciousness that lie beyond the reach of analogy—and therefore of scientific understanding. The first includes creatures whose sensory apparatus seems vastly different

from ours. The second is the realm of sensations which we have not experienced—such as the case of the scientist Mary or creatures whose range of vision, hearing, smell, or touch extends far beyond ours. Dogs, for an obvious instance, experience sounds and smells that are far beyond the sensitivity of human sensory apparatus. Also, some insects are capable of experiencing light which is far outside the frequencies available to human vision.

But, it is appropriate to ask whether these sensations are genuinely beyond the reach of analogy. It is possible, for example, that the machinery of bat sonar is closely akin to the sensory apparatus of quite different creatures, and this similarity may suffice to allow us to grasp their experience. As it happens, there is evidence that whales and dolphins also employ echolocation. More to the point, there is considerable evidence that blind human beings employ echolocation. Furthermore, studies demonstrate that humans with normal vision can be trained to employ echolocation (Schwitzgebel and Gordon, 2000). In retrospect, this should not surprise. Evolution is conservative. Abilities that prove useful to one species are likely to appear in other species as well.

Of course, Nagel may be undeterred by this result. He may assert that, though humans can also employ echolocation, it is quite possible that the human experience of echolocation is quite different from that of the bat. However, it is probable that the bat's sensory machinery emerged as a version of that employed by other creatures. Certainly, neither Nagel nor we can rule this out of the realm of possibility. Further, by noticing the precise ways in which a bat's brain processes this information, which areas of the brain are employed and which neural connections are present, we may well gain additional insight into the bat's sonar experience.

But, Nagel may be quick to note that the above claims can prove only that his example of echolocation was unfortunate. It remains possible that other modes of sensation or other sensations lurk beyond the reach of human experience and therefore of scientific understanding via analogy. That is the point of Frank Jackson's example of the scientist Mary.

Jackson's example is particularly difficult for consciousness researchers because it appears that human beings have no way to understand what simple sensations are like without experiencing them. Complex sensations, like the taste of chocolate or of wine, can be analyzed into their constituent sensations. If those simple constituent sensations are similar to those the researcher has experienced, the scientist will understand the nature of the complex sensation. This would be similar to an account provided by a wine reviewer. A wine reviewer will seek to give readers a sense of how a particular wine will taste by giving an account of the various flavors that a particular wine offers. In the case of simple sensations, however, no such analysis is possible. So, if the researcher has not experienced it, he or she has no way to determine what a particular simple sensation is like. Thus, Frank Jackson claimed the color red would be unfathomable for Mary prior to her experience of it.

But, we can nonetheless ask whether such alien, but simple, sensations are genuinely beyond the reach of analogy. To focus our reflection, we can employ the example of canine hearing, since no human being is able to experience the high pitched sounds that



dogs can hear. Researchers know that dogs are able to sense extremely high pitched sounds because dogs react to these sounds, but human beings do not.

There are at least four strategies researchers might employ to gain a sense of the canine experience of high pitched sounds. For one thing, it is possible scientists will discover that differing species will have similar experiences at common points in their range of hearing, so that sounds near the upper limit of human hearing will be experienced in the same way as sounds near the upper limit of canine hearing. In addition, it is possible that careful analysis of the mechanics of processing sound waves will yield insight into the way in which particular sounds are experienced. Additional insight may be gained from the fact that the range of human hearing contracts with age. Young people are able to hear sounds of far higher pitches than older people (For an amusing example of one consequence of this difference, see Vitello, 2006.). This would allow researchers to compare the descriptions young people offer of high pitched sounds with the descriptions older people provide of sounds near the upper limit of what they are able to hear. Researchers who compare and contrast these reports and correlate them with the physiology of hearing of people who possess differing ranges of hearing may then be able to devise theories that will enable them to determine the sensations of other species and correlate them with the sensations of human beings. Lastly, based on their studies of the physiology of hearing and comparative analysis of the hearing ranges of human beings of differing ages, researchers may be able to construct devices able to produce sounds analogous to those experienced by other species. It is entirely true that none of these techniques will yield certain knowledge of the experience of other species or of individuals with different ranges of sensation than our own. Nonetheless, a reasonable degree of probability is commonly sufficient for the needs of science. Also, each of us has no more than reasonable probability of understanding what other human beings are experiencing, yet we are often confident that we know their moods and sensations.

Any conscientious researcher will hasten to note that the approaches listed above may fail or prove inadequate. Nonetheless, there is presently little reason to believe they must in principle fail, and there is little reason to believe it will never be possible to devise other methods as our understanding increases. This conclusion applies to the present time. It is possible that in the future researchers will uncover significant reasons to conclude we can never become aware of the sensory experience of other creatures, but we have no such information at present.

In sum, there are reasons to remain confident that science will continue to successfully employ analogy and a more sophisticated understanding of the function of neural machinery to further our grasp of the conscious experience of other beings. The preceding does not demonstrate that science will overcome the challenges of discerning the complete chain of causal connections that lead from brain states to states of awareness or of devising an adequate theory of the relation between brain states and states of awareness. This essay only supports the conclusion that there is presently no reason to believe that science is doomed to fail in this endeavor.

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<sup>1</sup> Though Chalmers explicitly states that states of consciousness are complex, he does not reveal the way in which he believes they are complex (Chalmers, 1995, p. 211). If he means only that the contents of our conscious states are complex, the point has no relevance to the present discussion. If, however, he means to assert that conscious states are complex, then his claim that states of consciousness have no structure becomes mysterious.

<sup>2</sup> Of course, if string theory is correct, these entities are actually minute strings, existing at the Plank Length, vibrating in distinctive ways (Greene, 1999, pp. 13--4). If this view is correct, subatomic particles, though scientists presently believe they are simple, are not what they appear to be. Nonetheless, string theory remains hotly contested, and the final story of the ultimate nature of fundamental entities may be quite different.

<sup>3</sup> Ned Block points out the difference between 'access consciousness' and 'phenomenal consciousness' (Block, 1995). Our senses continually provide us with a stream of data necessary for ordinary function. For example, to stand erect we need a vast array of information about the configuration of our body and the relative position of our limbs. Without this information, we cannot maintain a standing posture. However, we are generally unaware of this information unless something goes awry. Also, when driving, we contrive to remain in the center of the right lane, maintain constant speed, and negotiate curves in the road while being engrossed in other matters. So, we must employ visual and tactile information to stay on course and avoid mishap, but we are typically unaware of it. These sensations are part of 'access consciousness'. They are available to us, but we are generally unaware of them. But, if we step into a rut or notice brake lights flashing in front of us, we immediately focus our attention on these data streams, and they enter into 'phenomenal consciousness'. The difficulties that concern Harnad are those of 'phenomenal consciousness', the sensory data that enters into our awareness.

<sup>4</sup> As Moore says, "When we try to introspect the sensation of blue, all we can see is the blue: the other element is as if it were diaphanous" (Moore, 1903, p. 450).

<sup>5</sup> Researchers would not be able to observe these conscious states directly. Rather, directly observed data, coupled with a theory of the sort Nagel envisages, would allow inferences about the experimental subject's conscious experience.

<sup>6</sup> This presumes that the frog has experience in Block's sense of phenomenal consciousness. It is entirely possible the frog does not have experience of this sort, but has access consciousness only. A number of studies have shown that experimental subjects must receive a stimulus for about ½ second to have phenomenal consciousness (Koch, 2004, 205--16). They nonetheless have access consciousness because they are able to react to the stimulus even though they have no experience consciousness of it. Koch believes there is a simple explanation for the difference. Actions that require an exceedingly quick response would not enter phenomenal consciousness and need not do so. Responses that benefit from greater flexibility or a time lapse between stimulus and response enter phenomenal consciousness, Koch speculates. Hence, as a practical matter, Koch presumes that responses that occur only after some delay require phenomenal consciousness (Koch, 2004, 11--2). Since the frog must react very quickly to make its



living catching flies, it is likely it lacks conscious awareness of its actions.

<sup>7</sup> The research of Lettvin, et al., 1959, demonstrates that frogs' neurons respond to sharp edges and contrast, the curvature of an edge, the movement of an edge, and local dimmings. Taken together, these do not construct an image of a fly. This latter point is driven home by the additional observation that it is easy to fool frogs by dangling small objects in their field of vision. (Lettvin, et al., p. 1941). Humans, on the other hand, have a far richer experience of flies. We are able to distinguish flies from other insects and from small objects. We think of them as having segmented bodies, and we are aware of the distinctive motions of their various body parts. To be sure, processing all this information requires considerable time, and that is part of the explanation of why we are unable to catch flies with our tongues.

<sup>8</sup> This example requires suspension of disbelief, since Mary's body would not be black and white, and it would be exceedingly difficult to contrive black and white food only. Nonetheless, this difficulty does not undermine the force of the example, since it is designed only to make vivid the claim that Mary could not genuinely comprehend a sensation which she had not experienced.



**Reports from the October 2006  
Executive Committee Meeting  
Samford University  
Birmingham Alabama  
By  
James R. Rayburn, Secretary**

**Call to Order**

**Officer Reports (B)**

1. **Board of Trustees**, Eugene Omasta

Members of the Board of Trustees of the Academy remain active in the affairs of the Academy including participation at the spring and fall Executive Committee meetings and serving on committees of the Academy. The trustees meet annually with the elected officers of the Academy and members of the Budget and Finance Committee at a luncheon during the annual meeting.

2. **President**, David Nelson

1. **Committee Structure:**

Since the AAS Constitution specifies that the First Vice-President (President elect) will appoint chairs and members to all committees, I first became familiar with the entire committee structure of AAS just last year. The appointment task is a significant one that necessitates effective participation of many other members of the academy. Nobody is aware of the diverse abilities of all academy members, or even knows the entire membership. Doubtlessly, many willing and interested people within the academy are never approached. I would encourage the AAS officers and membership routinely to refer the names of potential nominees to the first Vice-President, so that he / she can appoint members who are interested and enthusiastic. There are some committees that never meet or do anything. These committees probably need new members to be appointed. I have frequently contacted sectional chairmen to solicit the names of potential committee members. For the AAS to remain a strong, effective, and viable organization, we need to have broad representation of competent scientists from a diversity of institutions and geographic regions. In the future, let us all contribute the names of nominees whom we would like to recommend to the First Vice-President.

2. Although the Auditing Committees have not been functional for several years, I filled the positions for these two committees.

**Senior Academy:**

Sergey Belyi (2007) Mathematics, Troy

Robert Angus (2007) Biology, UAB

**Junior Academy:**

Henry Barwood (2007) Mathematics and Physics, Troy

Govind Menon (2007) Mathematics and Physics, Troy

Hopefully they can review the financial records of the AAS and AJAS sometime during the spring meeting at Tuskegee. The schedule will need to be coordinated with the respective treasurers (AAS and AJAS).

**3. Present vacancies on AAS Committees for which we need members:**

Committee on Research (1 vacancy)

Committee on Place and Date of Meeting (3 vacancies)

Committee on Public Relations (staggered 4-year terms)

(1 vacancy- must be past president)

Resolutions Committee (1 vacancy)

Mason Scholarship Committee (1 vacancy)

Committee on Development (not active, reactivate?)

Presently there is no Committee Description for the Resolutions Committee in the AAS Constitution and By-laws. Should we authorize such a description to be formulated and considered in the future?

4. During the AAS Executive Committee Meeting on 15 March 2006 at Troy University, Larry Davenport (in the Presidential Report) proposed that the academy solicit patrons for the Journal of the Alabama Academy of Science, at a cost of \$500 per ½ page space in the journal. Members were encouraged to pursue potential patrons: Alabama Power Co, Thompson/Cole, etc... We need to continue to pursue potentially interested organizations.

5. Kenneth R. Sundberg from Troy University submitted a refund check payable to the AAS for \$ 5,758.19. It represents a refund of the account for local arrangements from last year's spring meeting at Troy University. Receipts there totaled \$ 12,588.00; expenses were \$ 6,829.81. The balance was refunded to AAS in the check, which has been given to our treasurer, Taba Hammisou (JSU).

**6. Proposed Symposium 2007 (Friday morning at the Tuskegee Meeting):**

“HURRICANE IMPACTS ALONG THE GULF COAST” (Tentative)

Meteorology - Keith Blackwell (USA)?

Engineering – Scott Douglass (USA) CANCELLED

Sociology – Steve Picou (USA) CANCELLED

Biology – John Dindo (DISL)

Biology- John Valentine (DISL)

Nursing - Erica Prior & Pam Autrey (UAB)

Environmental Policy & Information Center – Pete Conroy (JSU)?

(Other Potential Speakers Pending)

3. **President Elect**, George Cline

I have been working with the President to find people to fill committees. We also have discussed the process of filling the various committees. Assisted in discussions regarding the Symposium and the Banquet Speaker.

Ellen Buckner and I did the site visit to Tuskegee University in preparation for the Spring Meetings. We examined the facilities, and we discussed the location for the Junior Academy meetings. Everything appears to be on track for the meetings 28 Feb- 2 March. One source of concern is the availability of laptops and projectors.

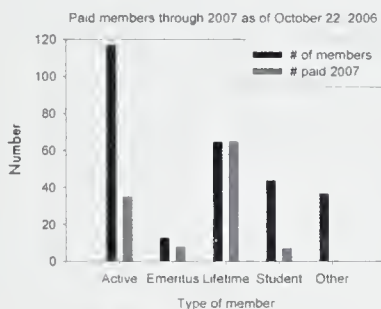
Spoke with Ken Roblee about 2<sup>nd</sup> VP duties and discussed nominations for the Board of Trustees. Will continue these discussions through the year.

4. **Second Vice-President**, Kenneth Roblee

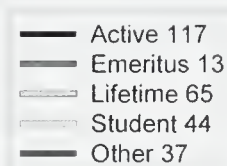
No Written report submitted.

5. **Secretary**, James Rayburn

1. I formatted the reports and minutes from the March meetings as requested by the Editor to be published in the Journal in June. I was concerned about publishing the minutes before we met in October to review them. (The reason this happened is that the journal is catching up in its publication date). I sent an email requesting approval as Larry Krannich suggested. Is this how we are going to approve minutes from now on?
2. I provided 3 sets labels including 2005 (not paid 2006) and 2006 memberships to Sue Bradley for mailing the Journal.
3. I provided Excel worksheets of not paid members to Mark Meade in June 2006.
4. In October I sent reminders to current members reminding them to pay dues for next year. I am preparing two more mailing one for November and January 07.
5. One of our members recently died, Shawn B. Allin of Spring Hill.
6. Our current membership is 276 members including Libraries and others.
7. We have 117 Active members (30% paid for 2007), 13 Emeritus (60% paid for 2007), 65 Lifetime, 44 Student (16% paid for 2007) and 37 other members.
8. If current membership stays stable we can expect \$3,065.00 more in dues. We have already received \$1,025.00 in dues for 2007. Last year dues for 2006 totaled \$5,290.00



Membership Breakdown AAS  
October 22, 2006



## 6. Treasurer, Mijitaba Hamissou:

**Beginning Balance (03-14-2006)** **\$ 1,780.31**

### A. Income

#### **April**

Membership	2,110.00
Science Fair	5,736.25
Mason	5.00

#### **May**

Membership	415.00
Journal support	128.70
AAS Journal (pub. Income)	200.00
Membership/interest/others	282.17

#### **June 2006**

Science Fair	8,502.00
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#### **July**

Money transfer to Compass	4,523.20
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#### **August 2006**

Science Fair	916.00
Membership	
Journal support	100.00

#### **September/October**

Membership	340.00
Royalty	83.91
Journal	
Other	

**Total Income** **\$24,815.25**

### B. Expenses

#### **March 15/April**

Partial 2006 meeting expenses	612.00
Gorgas/Mason scholarships/travel grants	1375.00



Bank charges	113.00
JASS expenses	1,275.00
Honoraria	350.00
<b>May</b>	
Honorarium	350.00
Science fair	5,012.50
<b>June</b>	
Science Fair	9,000.00
<b>July</b>	
JAS Honorarium	1,250.00
Honorarium	700.00
Mason Scholarship	1,000.00
Gorgas travel	1,823.20
<b>August</b>	
Honorarium	350.00
Journal	114.00
<b>Sept. / October</b>	
Honorarium	350.00
Scholarship	750.00
JAS supplement	30.38
Mailing	78.00
<b>Total expenses this quarter</b>	<b>\$24,533.08</b>

#### **The Academy Financial trend March 15, 2006 – October 15, 2006**

##### **March 15, 2006**

cd (1) + cd(2) +cd(3)	\$56,051.17
Saving account	\$1,258.60
Money Market	\$2,072.04
Checking account (per statement)	\$1,780.31
<b>Total assets all accounts (03/06)</b>	<b>\$61,162.12</b>

##### **October 20, 2006**

cd(1) + cd(2) +cd(3) + <b>cd(4)*</b>	\$56,560.38
Saving account	\$1,259.50
Money Market	\$2,833.36
Checking account (as of Oct. 20)	\$791.05
<b>Current assets all accounts (010/20/06)</b>	<b>\$61,444.29</b>
(*) New cd purchased	

## 7. **Journal Editor**, Safaa Al-Hamdani

- April issue of the volume 77 has been released successfully.
- July and October issue of volume 77 is in the process of completion.
- I would like to suggest that the abstract should be submitted electronically to one location. The abstract should be written following specific criteria to standardize for publication.
- Miss Sue Bradley has resigned from her responsibilities. I have selected a local replacement.
- The journal style and manuscript organization has improved following specific standardized criteria.
- Instructions to the author have been revised.

## 8. **Counselor to AJAS**, B.J. Bateman

2006 Annual Report of the Alabama Junior Academy of Science and the Junior Science and Humanities Symposium

State Officers/Counselors Meeting

The State Officers and the State Counselors met at the Birmingham Southern College to discuss the State Officer's roles for the upcoming year (2005-2006).

Fall AAS Executive Meeting

The State Counselor (B. J. Bateman) was unable to attend the Fall Executive Meeting.

### **Annual Meeting:**

The 2006 Annual Meeting, like all previous meetings of AJAS, was shared jointly with the Alabama Academy of Science. The host institution was Troy University. Ken Sundburg was the local arrangements for the AJAS, B. J. Bateman, Counselor to the AJAS, and Wanda PhiHips and Henry Barwood, Associate Counselors, planned registration procedures, space needs, and arrangements for the AJAS-JSHS social and banquet. Registration was held at the Hampton Inn. Highlights of the program were:

- (1) **Paper Competition** - The paper competition was conducted on Friday morning in McCall Hall. Rahul Goli was chosen to be the overall winner and would therefore represent Alabama in national competition held at Albekerque NM. The other four state winners (Omar Ahmed, Lacy Casteel, Marshal Everett, and Paige Poole) and Linda Kanipe.
- (2) **Banquet** - More than One hundred students, teachers, university professors, and members of business, industry and government shared the Friday night banquet. A major part of the after-dinner program was the recognition of the first and second-place winners of the paper competition, and other competitions

**(3) Business Meeting** - The customary AJAS business meeting was held on Saturday morning. This provided a time for awarding a plaque to the outstanding region, a certificate and a check to the outstanding teacher(s), and other awards.

**Winners and Awards 2006 “Best with the Least”**

Biological Sciences	Libby Swift	The Altamont School
Engineering	Christina Carroll	Brooks High School
Humanities	Diana Patterson	JC IB
Physical Science	Meridith Daniels	Brooks High School

**Second Place**

Biological Sciences	Linnea Pepper	JCIB
Engineering	Brandon Kirkland	JCIB
Humanities	Diana Patterson	JCIB
Physical Science	Ray Smith	JCIB

**First Place**

Biological Sciences	Rahut Go II	The Altamont School
Engineering	Omar Ahmed	Florence High School
Humanities	Marshal Everett	Shoals Christian School
Mathematics	Paige Pöote	JCIB
Physical Science	Lacy Casteel	Brooks High School

**Research Grant Award**

Meredith Daniels	\$109.00
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**AAAS Award**

Outstanding Teacher Award	Vlckf Farina
Outstanding Region	Northwest

**Newly elected officers for 2006-2007:**

President	Meredith Daniels	Brooks High School
Vice-President	Brittney Daniels	Brooks High School
Treasurer	Omar Ahmed	Florence High School
Secretary	Liz Raballais	Florence High School
Event Coordinator	Chris Pjare	JCIB School

JSHS Participants Attending the Annual Meeting  
 46 students, sponsors, and counselors attended the annual meeting as JSHS participants.

Students

Brandon Kirkland Diana Patterson Paige Poole Chris Phare Ray Smith Linn Trann Emily Smith Ashley Cockrell Sarah Erling Linnea Pepper Melisa Smith	JCIB
Will McWane Libby Swift Rahul Goti	The Altamont School
Meredith Daniels Brittney Bradford Christina Carroll Lacy Casteel Jessica Swinea	Brooks High School
Liz Raballais	Florence High School
Lauern Bradfod Lacy Casteel Marshall Everett Omar Ahmed Jennifer Taylor	President Secretary Shoals Christian School Treasurer Vice President



### Adults

Billy Sanders	Assistant to the Counselor
Gene Omasta	Assistant to the Counselor
Wanda Phillips	Associate Counselor
B. J. Bateman	Counselor
Linda Kanipe	Northwest Regional Counselor
Henry Barwood	Associate Counselor
Vicki Farina	Brooks
Catherine Shields	Central Region Counselor
Conrad Smith	JCIB
Thersa Smith	JCIB
Rita Phare	JCIB
Robert Phare	JCIB
JacqJen Poole	JCIB
Bobby Patterson	JCIB
Randy Kirkland	JCIB
Doreen Pepper	JCIB
Susie Bradford	Brooks
Donna Casteel	Brooks High School
Joan Lee	Florence High School
PamTaylor	Florence High School
Rafeeq Ahmed	Florence High School

9. **Science Fair Coordinator**, Virginia Valardi

No Written report submitted.

10. **Science Olympiad Coordinator**, Jane Nall

Perhaps still the best kept secret in the State, many volunteers of Alabama Science Olympiad provide students the opportunity to participate and compete in Science Olympiad. Teachers, parents, coaches, bus drivers, university professors, university work study students, and other volunteers work to provide the students of Alabama the joys of “doing science” in an arena resembling athletic tournaments.

Herculean efforts are made each year by staff and volunteers on several university campuses, and teachers, parents, and students of over 200 public and private schools, so they might experience the joys and thrills of doing lab hands-on science.

Placing 10<sup>th</sup> in the nation for membership, Alabama Science Olympiad continues to grow in numbers of teams and participation at all levels. For several years now, because of the number of teams registering in Alabama, two teams in both Division B (grades 6-9) and Division C (grades 9-12) have advanced to the national competition following successfully winning at regional and the state tournaments. Only the top ten states in membership receive the second invitation at the secondary level to compete at the national tournament. The elementary levels compete at various local and regional tournaments.

The University of West Alabama, Jacksonville High School and Auburn University host an A2 tournament (grades 4-6) and report they have a great time, and they are already planning this year's tournaments. There will be five regional C tournaments and four regional B tournaments. We really need at least one more B host! State Alabama B will be held at Huntingdon College and Alabama C will be on the campus of Samford University in April.

Science Olympiad events address the National Standards for Science Education and comprise all areas of science including astronomy, meteorology, experimental design, genetics, anatomy, process skills for life science and biology, chemistry and polymers, physics, earth science and fossils, and water quality and the environment, map skills, GIS and remote sensing as well as building events such as a Rube Goldberg-like device, robot, bottle rocket, plane, bridge and tower building, musical instruments. Alternating events in taxonomy include topics of trees, amphibians and reptiles, birds, insects.

Director Nall is in search of more universities willing to host tournaments! Consider showcasing your campus and join us in the fun! The State Director is appointed by the Alabama Academy of Science. To date Alabama has been lead by two directors – 1985-1996 Mr. Steven Carey, University of Mobile and 1997-present Ms. Jane Nall, Spanish Fort High School and the University of Mobile.

11. **Counselor to AAAS**, Steve Watts

The annual meeting for the AAAS affiliates convened on February 15-19, 2007 in San Francisco, California.. All state Academies maintain an association with the American Association for the Advancement of Science. We are members of the Section on Agriculture, Food and Renewable Resources and the Section on General Interest in Science and Engineering. The theme of this years meeting “Science and Technology for Sustainable Well-Being” brings together provocative thinkers and decision-makers for a wide range of symposia, plenary lectures, topical lectures, seminars, presidential tracks, and other sessions that address global and national issues in health, energy, the environment, economic development, education, terrorism, science frontiers, and more.

We welcome the opportunity for any AAS member to attend the AAAS meeting on our behalf. Information about the AAAS can be obtained at [www.aaasmeeting.org](http://www.aaasmeeting.org).

12. **Section Officers**

- I. **Biological Sciences**, Brian Burnes  
No Written report submitted.
- II. **Chemistry**, Houston Byrd  
No written report submitted

**III. Geology & Earth Sciences, Mark Puckett**

No written report submitted

**IV. Geography, Forestry, Conservation & Planning, Greg Gaston**

No written report submitted

**V. Physics & Mathematics, Nirmol Podder (by Kenneth Roblee)**

In the 2006 annual meeting of the AAS at Troy University, our section hosted a total of 19 presentations, which is an increase over the previous few years. Two of these were given by students. We also had an invited lecture this year, given by Dr. A. Kumar of Tuskegee University.

During the business meeting the section members elected Dr. A. Kumar of Tuskegee University as section vice-chair for the 2006-07 academic year. For the 2006-07 academic year, Dr. Brian Thompson of the University of North Alabama will be the section chair.

We plan to keep building this section by using the list of math and physics department contacts in the state compiled by Dr. Krannich to recruit speakers for the spring 2007 meeting.

**VI. Industry & Economics, Marsha Griffin**

No written report submitted

**VII. Science Education, Lori Cormier**

No written report submitted

**VIII. Behavior & Social Sciences, Cheryl Bullard**

No written report submitted

**IX. Health Sciences, Virginia Hughes**

I. Recruited judges for the annual meeting

II. Contact the following clinical laboratory science program directors to inform them of the spring annual meeting in Tuskegee: Dr. Janelle Chiasera - UAB School of Health Professions Dr. George Harwell - University of South Alabama Dr. Cheryl Davis - Tuskegee University

III. Contacted the Cytotechnology program directors: Sonya Griffin - Auburn University Montgomery Dr. Vivian Pijuan-Thompson - UAB

**X. Engineering & Computer Sciences, Marietta Cameron**

No written report submitted

**XI. Anthropology, Phillip Koerper**

No written report submitted

## **XII. Bioethics & History/Philosophy of Science, Keith Gibson**

No written report submitted

### **13. Executive Officer, Larry Krannich**

Since March, 2006, I have been involved in the following activities associated with the Executive Director of the Alabama Academy of Science position:

1. Discussed with Prakash Sharma materials needed concerning arrangements, program booklet needs, and deadlines associated with the annual meeting of the Academy to be held on the Tuskegee University campus, February 28 - March 3, 2007.
2. Prepared letters to Alabama colleges and universities to solicit financial support for the Journal for distribution after November 1.
3. Prepared the Call for Papers for the 84<sup>th</sup> meeting of the Academy that will be distributed to all Section Chairs in hard and electronic copy after November 15<sup>th</sup>.
4. Prepared the Annual Meeting Announcement and 2007 Dues mail-out and sent these to the Secretary for mailing.
5. Designed bookmarks advertising the Academy and participation in the annual meeting. These will be distributed statewide in mid-November.
6. Requested from the American Chemical Society approval for co-sponsorship of the annual state-wide Undergraduate Chemistry Research Symposium.
7. Updated the fliers and letters being sent to all Alabama chemistry faculty to solicit the participation of undergraduates and Alabama college and university Chemistry faculty in the 3<sup>rd</sup> annual Undergraduate Chemistry Research symposium to be held in conjunction with the annual meeting of the Academy. The local sections of the American Chemical Society in the State are being contacted to assess their willingness to again co-sponsor this state-wide undergraduate research symposium with the Academy
8. Represented the Academy and the Gorgas Scholarship Committee at the joint booth at the annual ASTA meeting.

### **Committee Reports (C)**

#### **1. Local Arrangements, Prakash Sharma**

No written report submitted

#### **2. Finance, Eugene Omasta**

The Alabama Academy of Science continues to be in excellent financial condition with total assets of \$61,444 as of October 20, 2006. In addition, this figure does not include a return of \$5,758 received from Troy University which hosted last year's annual meeting. The assets since 2001 as reported at the Fall Executive Committee meetings and the year end assets are listed on following page:



Period	Assets	Change	Period	Assets	Change
1/1 - 10/12/2001	\$71,763		1/1-12/31/2001	\$75,813	
1/1-10/12/2002	\$72,197	\$434	1/1-12/31/2002	\$72,813	-\$3,000
1/1-10/12/2003	\$71,403	-\$794	1/1-12/31/2003	\$74,800	\$1,987
1/1 - 10/26/2004	\$74,265	\$2,862	1/1-12/31/2004	\$74,610*	-\$190
1/1-10/26/2005	\$63,895	-\$10,370	1/1-12/31/2005	\$65,561*	-\$9,049
1/1-10/20/2006	\$61,444	-\$2,451			

The large decrease in assets during 2005 was a result of declining membership and an increase in Journal expenses due to printing back issues of the Journal that year. In an effort to increase membership, Dr. Krannich sent post card reminders, in December, 2005, to all persons who were either currently members or have been members of the Academy at some time during the past 5 years. Dr. Rayburn sent postcard reminders to current members this fall. The results of these efforts should be reflected in the year end assets.

The Academy should continue to explore ways of increasing revenues including seeking the best investment rates for our assets and ways to increase membership.

### 3. **Membership**, Mark Meade

With Dr. Rayburn's help (AAS secretary) I mailed out nearly 100 reminders to recent members who have not paid annual dues. I also e-mailed all academy section chairs reminding them to contact persons within their section and remind them of dues.

### 4. **Research**, Steve Watts

This year 19 students (the same as last year) applied for travel awards to the Troy University meeting. All were presenting papers or posters. All students were from out of town and were each awarded \$35. Budgeted amount for travel is \$750 and we encumbered \$665. In addition, 5 students (down from 4 last year) applied for research grants. The committee is evaluating the grants and all of these will be awarded in full (\$1,250 of the budgeted amount of \$2,400). Support for book purchases are no longer allowed this year, nor is travel to other conferences (decided at last fall meeting). Twenty-three students (down from 40) have applied for the Research Paper/Poster Competition in several sections. New (slightly modified) evaluation forms and suggested criteria were sent to all section chairs and are now on the web.

All categories of awards and activities were handled electronically for the third year. Several minor modifications may be needed for next year, but in general electronic submissions greatly improved the process and eliminated a gruesome paper trail. Richard Hudiburg has done an outstanding job in fine-tuning the process of submission.

This year the paper/poster competition will be held on Thursday only, with the banquet on Thursday night where winners will be announced.

5. **Long-Range Planning, --**  
No written report submitted
6. **Auditing, Senior Academy, Sergey Belyi**  
No written report submitted
7. **Auditing, Junior Academy, Henry Barwood** By Dr. Govind Menon, Auditor  
Alabama Junior Academy of Science

July 2005- July 2006 Audit of Alabama Junior Academy of Science Financial Records  
This is a report of the Alabama Junior Academy of Science Auditing Committee for the July 2005-July 2006 financial year. I have examined the books provided by the Alabama Junior Academy of Science Treasurer, Dr. B.J. Bateman. We are satisfied ourselves that the receipts and expenditures, as presented to us, are correct and that all expenditures are legitimate expenses.

The net worth as of June 30, 2006 is \$11,808.50

8. **Editorial Board & Associate Journal Editors, Thane Wibbels**  
No written report submitted
9. **Place and Date of meeting, Mark Meade**  
No written report submitted
10. **News Letter, --**  
No written report submitted
11. **Public Relations, Larry Davenport**  
No written report submitted
12. **Archives, Troy Best**  
No written report submitted

13. **Science and Public Policy, Scott Brande**  
My Favorite Web Resources on the Evolution/Creationism controversy  
By: Scott Brande, Ph.D. CHM-289, UAB  
Birmingham, AL 35294 sbrande@uab.edu  
The National Center for Science Education [www.ncseweb.org](http://www.ncseweb.org)

My number one stop for information with current news and extensive resources and links. Categories include teacher resources on creationism and evolution, extensive coverage of recent court cases (Dover, Cobb County,...), references and reading lists, book reviews, and much, much more.

National Science Teachers Association <http://www.nsta.org/>

The professional organization for science teachers, with a website that provides a modest set of links to evolution resources for teachers at <http://www.nsta.org/220/>

including a Q&A for teachers links to current news, the NSTA position statement on teaching evolution, and web links.

Understanding Evolution is a “non-commercial, education website, teaching the science and history of evolutionary biology. This site is here to help you understand what evolution is, how it works, how it factors into your life, how research in evolutionary biology is performed, and how ideas in this area have changed over time. The site is collaboration between the University of California Museum of Paleontology and the National Center for Science Education. <http://evolution.berkeley.edu/> The site includes evolution in the news, profiles of scientists, an extensive collection of searchable lesson plans from K to 12, self-teaching modules on Evolution 101, and original content about interesting organisms in action from bacteria to bugs.

American Association for the Advancement of Science [http://www.aaas.org/news/press\\_room/evolution/](http://www.aaas.org/news/press_room/evolution/) The front page to extensive resources, including coverage of educational issues in the news, resources for teachers (including a talking points Q&A). <http://www.aaas.org/spp/dser/>

At the Programs/Science and Policy tab, you’ll find a special section, the AAAS Dialogue on Science, Ethics, and Religion. Especially interesting is the availability on the web of audio files of most of the public lectures sponsored by AAAS since 2002. [http://www.aaas.org/spp/dser/02\\_Events/Lectures/02\\_LectureArchive.shtml](http://www.aaas.org/spp/dser/02_Events/Lectures/02_LectureArchive.shtml)

AAAS has just published a new book, *The Evolution Dialogues: Science, Christianity, and the Quest for Understanding*, “his unique and extraordinary resource presents in plain language and in fewer than 200 pages a new conversation on evolution and Christianity.” Highly recommended National Academies of Science

<http://nationalacademies.org/evolution/> The National Academies of Science is the nation’s advisor on issues of science, engineering and medicine. It publishes books and reports, including those on evolution research and education. Important issues include “Teaching About Evolution and the Nature of Science” and “Science and Creationism: A View from the National Academy of Sciences”.

TalkOrigins.org <http://talkorigins.org/>

One of the largest archives of information about the evolution/creationism controversy on the web. Here you will find a “collection of articles and essays... The primary reason for this archive’s existence is to provide mainstream scientific responses to the many frequently asked questions (FAQs) that appear in the talk.origins newsgroup and the frequently rebutted assertions of those advocating intelligent design or other creation creationist pseudosciences”.

The Pandas Thumb

<http://www.pandasthumb.org/> A “virtual” (web) publication in which people gather to discuss evolutionary theory, critique the claims of the antievolution movement, defend the integrity of both science and science education, and share good conversation. Although not a tightly organized and arranged as other websites, The Pandas Thumb includes a wealth of information along with casual banter. Individual posts can be amusing and fun to read.



Dr. Kenneth Miller’s annotated bibliography <http://www-personal.k-state.edu/~kbmill/scifaith.html> Dr. Miller is a practicing Catholic and the co-author of the biology textbook recommended by teachers at the Dover Area School District, Pennsylvania and in Cobb County, Georgia, and opposed by Intelligent Design advocates. Legal actions in both locations lead to important trials that revealed much about the nature of the evolution/creationism controversy in public schools. See Dr. Miller’s bibliography his extensive reading list on science and theology, theology of creation, and Christian environmentalism.

**14. Gardner Award, Prakash Sharma**

Fellow - Alabama Academy of Science (FAAS) Alabama Academy of Science

October 28, 2006

This is to request each and every member of this academy to publicize to individuals, heads of departments, deans and provosts of colleges and universities about this prestigious award. Please solicit nominations from individuals and different academic and industrial organizations for this award. The nomination should be forwarded to:

**Dr. P. C. Sharma, Chair**

Head of Physics Department,

Tuskegee University, Tuskegee, AL 36088.

Phone: (334) 727-8998; Fax: (334) 724-3917 e-mail: [pcsharma\(q\).tuskegee.edu](mailto:pcsharma(q).tuskegee.edu)

You are welcome to nominate by either e-mail or by mailing a hard copy. **The nominations should consist of the following documents:**

(i) Formal Nomination Letter, (ii) vitae and at least two letters of references from peers, administrators and one by an expert in area of his/her research, and (iii) one page citation that will be used for presentation of the award.

Anything missing from items (i, ii, iii) will result in rejection of the nomination. The closing date for nominations is December 20, 2006. The award will be presented in the “Annual Meeting of Alabama Academy of Science-Banquet”, on Thursday, March 1, 2007.

**Wright Gardner Award Committee Report Alabama Academy of Science**

**October 28, 2006**

The first meeting of the Alabama Academy of Science was held at Sidney Lanier High School, Montgomery, Alabama, April 4, 1924, in conjunction with the Alabama Educational Association Meeting. Wright Gardner was elected as an office bearer of the academy in this meeting. Through his early studies he became determined to make teaching and research his two goals for his life. The Wright Gardner Award was established, after the name of this great future looking scientist and educator, by the Alabama Academy of Science in 1984 to honor individuals whose work during residence in Alabama had been



outstanding. Persons nominated for this award have included researchers, teachers, industrialists, clinicians, scholars and active members and office bearers of the Alabama Academy of Science.

This is to request each and every member of this academy to publicize to individuals, heads of departments, deans and provosts of colleges and universities about this prestigious award. Please solicit nominations from individuals and different academic and industrial organizations for this award. The nomination should be forwarded to:

**Dr. P. C. Sharma, Chair, Wright Gardner Award Committee,**

Head of Physics Department,

Tuskegee University, Tuskegee, AL 36088.

Phone: (334) 727-8998; Fax: (334) 724-3917 e-mail: [pcsharma@tuskegee.edu](mailto:pcsharma@tuskegee.edu)

You are welcome to nominate by either e-mail or by mailing a hard copy. **The nominations should consist of the following documents:**

(i) Formal Nomination Letter, (ii) vitae and at least two letters of references from peers, administrators and one by an expert in area of his/her research, and (iii) one page citation that will be used for presentation of the award.

Anything missing from items (i, ii, iii) will result in rejection of the nomination. The closing date for nominations is December 20, 2006. The award will be presented in the “Annual Meeting of Alabama Academy of Science-Banquet”, on Thursday, March 1, 2007.

#### **15. Carmichael Award, Richard Hudiburg**

The committee looks forward to reviewing research articles published in Volume 78 of the *Journal of the Alabama Academy of Science* in 2006. The Emmett B. Carmichael Award will be announced during the 84<sup>th</sup> annual meeting in March 2006.

#### **16. Resolutions, --.**

No written report submitted

#### **17. Nominating committee, Kenneth Roblee**

No written report submitted

#### **18. Mason Scholarship, Mike Moeller**

Last spring we had six completed applications for the William H. Mason Scholarship. After reviewing all application materials the Scholarship Committee offered the \$1000 scholarship to Ms. Kelly Harbin. Ms. Harbin accepted the award.

The previous recipients of the William H. Mason Scholarship are:

1990-1991	Amy Livengood Sumner
1991-1992	Leella Shook Holt
1992-1993	Joni Justice Shankles
1993-1994	Jeffrey Baumbach
1994 -1995	(Not awarded)
1995-1996	Laura W. Cochran
1996-1997	Tina Anne Beams
1997-1998	Carole Collins Clegg
1998-1999	Cynthia Ann Phillips
1999-2000	Ruth Borden
2000-2001	Karen Celestine, Amy Murphy
2001-2002	Jeannine Ott
2002-2003	(Not awarded)
2003-2004	Kanessa Miller
2004-2005	(Not awarded)
2005-2006	Mary Busbee, Bethany Knox
2006-2007	Kelly Harbin

Attached to this report is a copy of an announcement that the committee plans to be sending soon to deans in schools of science and education within Alabama. Members of the AAS Executive Committee are encouraged to copy and disseminate this information.

## **19. Gorgas Scholarship Program, Ellen Buckner**

Effective 2006, the Gorgas Competition began accepting applications directly. A website was set up by Dr. Richard Hudiburg at [www.GorgasScholar.org](http://www.GorgasScholar.org). The Competition has been renamed the Gorgas Scholarship Competition and Alabama Science Scholar Search. In 2006 eighteen applications from 10 schools were received and all met the minimum criteria for consideration. Twelve finalists competed in the final competition at Troy University. Thirty-nine scientists from across the state gave of their time and expertise as judges for the competition, either as paper readers or judge of the final competition. Winners were announced and pictured on the website. Congratulations to Ms. Jennifer Taylor of Florence High School who was the winner in 2006 as well as a Finalist in the national Intel Science Talent Search. The Competition was highly successful in this, the first year of direct submission. The AAS and Gorgas Competition were featured in an article published in the Alabama Association of School Boards magazine Alabama School Boards in June.

The 2007 competition planning has been done. The website has been updated with the submission date of January 8, 2007. Note that the AAS meeting is very early this year making the need for speedy review of the papers an imperative! We plan to have the final judging completed by the first of February to announce finalists. AAS-Gorgas representatives were present at the fall meeting of the Alabama Science Teachers Association (ASTA). Fliers were sent statewide to all chairpersons

of high school science departments—both public and private. Numerous letters will be sent in the next month to students who have done internships, science fair projects or papers at the State level, and other groups (e.g. IB Schools, Governor’s School, CORD summer science graduates). AAS members are welcomed to submit names for individual letters (to teachers or students) inviting application. Send complete contact information to Dr. Buckner at [bucknere@uab.edu](mailto:bucknere@uab.edu). Applications to the Gorgas competition are limited to High School seniors.

The Gorgas Committee met this morning and welcomed Dr. Shane Sharpe to the committee. The committee reviewed information on the current status of the Legacy account. In addition, the committee has set up a checking account this year for the Gorgas funds. The account has Drs. Krannich and Buckner as signatory. It will be used for expenses of the competition. A teacher award for 2007 is under consideration to recognize those teachers who consistently encourage student’s participation. Changes for the 2007 meeting with the banquet on Thursday night will require some changes in the Gorgas Competition schedule.

Members of the AAS Executive Committee are asked to talk to teachers and encourage them to visit the website and invite their top science students to apply. To realize the potential that exists, teachers throughout the state must be aware of the Gorgas competition. AAS members are asked to assist by passing along the attached flier. Please visit the website at :[www. Gorgas S cholar.org](http://www.GorgasScholar.org)

Fall 2006 Report of the Gorgas Scholarship Committee Finances  
October 28, 2006

In Fall 2006 a checking account (Regions, Birmingham) was opened to handle expenses and publicity of the competition. The account is listed as Alabama Academy of Science- Gorgas Scholarship Program and Drs. Krannich and Buckner are signatory. Activity on the account to date is listed below:

Initial deposit form APF (expenses):	\$5728.00
Expenses:	
Mailing	\$618.22
ASTA Booth & Ad	\$300.00
Total remaining:	\$4809.78

**20. Electronic Media, Richard Hudiburg –**

I report the following activities:

1. Updated the main webpage for the AAS website and provided links to materials based on requests from the AAS president and Executive Director of AAS.
2. Complete the transmittal of the paper abstracts from the 83rd annual meeting of AAS to the Editor of the Journal of the Alabama Academy of Science. This process was completed in a timely manner.
3. Provided preliminary information and links for the 84th annual meeting.
4. Responded to various requests from the President of AAS, Executive Director of AAS and other members concerning changes to the AAS website.

5. The AAS website was migrated successfully to a new platform during June and July 2006 by the web hosting company, PowWeb.com.
6. There will be a specific proposal by the associate editors for electronic media, Marietta Cameron and Brian Toone, to redesign the AAS website.

### **Discussion**

During President Election Report the following took place:

The following were nominated to fill vacancy in board. Gene Omasta made the motion to vote these in.

Ken Marion

Jim Bradley

Ron Jenkins

Prakarsh Sharma

A vote taken and it was unanimous to accept these to fill in the vacancies.



## Members of Alabama Academy of Sciences (2007)

Kassidy, Alexander, Student  
 Safaa, Al-Hamdani, Active  
 Muhammad, Ali, Active  
 Sherita, Andrews, Student  
 Robert, Angus, Active  
 Arthur G., Appel, Lifetime  
 David, Arrington, Active  
 Sonja, Artis, Student  
 Jacary, Atkinson, Student  
 Shaina, Attoh, Student  
 Mark, Bailey, Lifetime  
 Basil, Bakir, Student  
 Laszlo, Baksay, Lifetime  
 Ronald, Balczon, Active  
 Michael, Barbour, Active  
 Wayne T. , Barger, Active  
 Amy Marie, Barr, Student  
 William J, Barrett, Emeritus  
 John, Barrett, Active  
 Brittani, Batts, Student  
 Robert P, Bauman, Emeritus  
 TE, Bearden, Lifetime  
 Daley T., Beasley, Student  
 John M, Beaton, Emeritus  
 Lee R, Beck, Lifetime  
 Peter, Beiersdorfer, Active  
 Sergey, Belyi, Active  
 Helen H., Benford, Active  
 Neil, Billington, Lifetime  
 Benjie, Blair, Lifetime  
 John, Boncek, Active  
 Larry R, Boots, Lifetime  
 Coartney, Boyd, Student  
 James T., Bradley, Lifetime  
 Malcom, Braid, Lifetime  
 Scott, Brande, Active  
 Andre , Braxton, Student  
 Lakisha, Brown, Student  
 David C, Brown, Lifetime  
 Lisa, Buchanan, Student  
 LW, Buckalew, Lifetime

Ellen, Buckner, Lifetime  
 Charles E, Bugg, Lifetime  
 Brian S, Burns, Active  
 Shuntele N., Burns, Active  
 Gayle L., Bush, Active  
 Houston, Byrd, Active  
 Malori, Callender, Student  
 Leslie, Calloway, Student  
 Sherell, Carey, Student  
 Marcqueia L., Carson, Student  
 Jan, Case, Active  
 Ashley Kay, Casey, Student  
 Gail H, Cassell, Lifetime  
 Tanushree, Chakravarty, Student  
 Misty, Chapman, Student  
 Kristen, Chappell, Student  
 Melissa, Charles, Student  
 Kimberly, Childs, Student  
 Janese D., Christian, Student  
 Cleary, Clark, Student  
 Ben A, Clements , Emeritus  
 George, Cline, Active  
 Andrew, Coleman, Student  
 Loretta A., Cormier, Lifetime  
 Megan, Cox, Student  
 Lonnie, Craft IV, Student  
 Thomas F, Craig, Lifetime  
 Johnathan, Crayton, Student  
 Amy, Crews-Oyen,  
 Anne, Cusic, Lifetime  
 J William, Dapper , Active  
 Larry, Davenport, Active  
 Henry W., Davis, Student  
 Richard, Davis, Active  
 WR, Davis, Lifetime  
 Floyd, Davis , Student  
 Lewis S, Dean, Active  
 Alvin R, Diamond, Jr, Active  
 Austin, Dixon, Student  
 Adriane, Dobson, Student  
 Keela, Dodd, Student

Steve, Donaldson, Lifetime  
 Lydia, Dorgan, Student  
 Tracy W., Duckworth, Active  
 Julian L, Dusi, Lifetime  
 Rosemary D, Dusi, Lifetime  
 Roland R, Dute, Lifetime  
 Hussain, Elalaoui-Talibi, Active  
 Geraldine M, Emerson, Lifetime  
 Matthew, English, Student  
 Oskar M, Essenwanger, Lifetime  
 Jenny, Estes, Student  
 Jeremy, Evans, Student  
 Whiney, Evans, Student  
 P. Taylor, Ezell, Student  
 Christine, Feeley, Student  
 Joe M, Finkel, Active  
 Sara, Finley, emeritus  
 Wayne H, Finley, emeritus  
 James H, French, Lifetime  
 Michael, Froning, Active  
 Teshome, Gabre, Active  
 Edward B., Garner, Student  
 Carolyn, Gathright, Active  
 Brittany, Gay, Student  
 Victoria K., Gibbs, Student  
 Keith, Gibson, Active  
 Kenneth R, Gilbert, Student  
 Fred, Gilbert, MD, Lifetime  
 Cameron W., Gill, Student  
 Leslie R., Goertzen, Active  
 Narendra Kumar, Govil, Active  
 Lamesha D., Greene, Student  
 Wendy, Gregory, Student  
 Marsha D, Griffin, Active  
 Jan , Gryko, Active  
 Robert T, Gudauskas, emeritus  
 Pryce “Pete”, Haddix, Active  
 James H, Haggard, Active  
 Rosine W, Hall, Lifetime  
 Mijitaba, Hamissou, Active  
 Shana, Hardy, Student  
 Victor, Harris, Student

Joseph G., Harrison, Active  
 Antonio, Haye0/s, Student  
 Leven S, Hazlegrove, Lifetime  
 Qinghua, He, Active  
 Paul Andrew, Helminger, Active  
 Justin, Hendricks, Student  
 B Bart, Henson, Active  
 Donald, Herbert, Active  
 Miriam Helen, Hill, Lifetime  
 Thandiwe, Hlatywayo, Student  
 Emily, Holden, Student  
 A Priscilla, Holland, Lifetime  
 Richard D, Holland, Active  
 Dan C, Holliman, emeritus  
 Harry O, Holstein , Active  
 Irina, Howard , Student  
 Candice, Howard-Shaughnessy, Active  
 Xing, Hu, Lifetime  
 Richard A, Hudiburg, Lifetime  
 Kelli, Hudson, Student  
 Virginia, Hughes, Active  
 Brenda W, Iddins, Active  
 Issac E., Igbonagwam, Student  
 Thomas S, Jandebeur, Lifetime  
 Brandon P., Jarman, Student  
 Li , Jiang, Active  
 Adriel D, Johnson, Lifetime  
 Ivy Krystal, Jones, Student  
 Ruth W, Kastenmayer, Active  
 Ellene, Kebede, Active  
 William E., Kelly,  
 Ashley D., Kennedy, Student  
 Jong Hwa, Kim, Active  
 Duk Kyung (Daniel), Kim, Active  
 Steve, Kimble, Student  
 Natalie, King, Student  
 Christopher , King, Active  
 Martha V, Knight, Active  
 Lawrence F., Koons, emeritus  
 Larry K, Krannich, Lifetime  
 Srinivasarao, Krishnaprasad, Active  
 Jeanne L., Kuhler, Active

Akshaya, Kumar, Active  
 Anne Marie, LeBlanc, Student  
 Cherline, Lee, Student  
 Aleck W., Leedy, Active  
 Pamela M., Leggett-Robinson, Active  
 Carol, Leitner, MD, Lifetime  
 Michel G, LeLong, Lifetime  
 Michael S, Loop, Lifetime  
 William K, Love, Active  
 James R, Lowery, emeritus  
 Adriane, Ludwick, Active  
 Christy, Magrath, Active  
 Ken Roy, Marion, Active  
 Julia E, Massey, Active  
 Juan Luis, Mata, Active  
 William K, McAllister, Lifetime  
 J Wayne, McCain, Lifetime  
 Amanda, McCall, Student  
 Jim, McClintock, Active  
 Vann, McCloud, Student  
 Stuart W, McGregor, Active  
 Teena M., McGuinness, Active  
 Matthew, McGuire, Student  
 Ellen W, McLaughlin, Active  
 Bonnie , Mcquitter-Banks, Active  
 Mark, Meade, Active  
 Victoria, Mechtly, Student  
 Joseph, Menefee, Student  
 Joe , Mills, Student  
 Deanna, Minisee, Student  
 Leana, Mitchell, Active  
 Stacy Tyrone, Mixon, Lifetime  
 Michael B., Moeller, Active  
 David, Mohammad, Student  
 Jack H, Moore, emeritus  
 Teresa Kelley, Moore, Active  
 Anthony G, Moss, Active  
 Christopher, Murdock, Active  
 Gerald, Murray, Lifetime  
 Henry David, Muse, Active  
 Gwen, Nance, student  
 Marione E, Nance, Active

Juan M, Navia, emeritus  
 David H, Nelson, Active  
 Bradley R., Newcomer, Lifetime  
 Ray, Neyland, Active  
 Alfred, Nichols, Active  
 Monica, Norton, Student  
 Samuel C., Nwosu, Student  
 Lumumba, Obika, Student  
 Benedict, Okeke, Active  
 Eugene, Omasta, Active  
 Albert, Osei, Active  
 William F, Osterhoff, Active  
 Janna, Owens, Student  
 Donald L, Parker, Lifetime  
 Scott C, Parrish, Lifetime  
 Glenn D., Person, Student  
 Mikel D., Petty, Active  
 Robert E, Pieroni, Active  
 James A, Pittman, Jr, Lifetime  
 Marshall, Pitts, Lifetime  
 Morgan S, Ponder, Active  
 Duane, Pontius, Active  
 Nichole L., Powell, Active  
 Mohammed A., Qazi, Active  
 Samiksha, Raut, Student  
 James, Rayburn, Active  
 Jarrod, Rayford, Student  
 Gerald T, Regan, emeritus  
 Philip D., Reynolds, Active  
 Velma, Richardson, Active  
 Alexander, Roberts, Student  
 Janet, Roberts, Student  
 Robin, Roberts, Lifetime  
 B.K., Robetson, Active  
 Edward L, Robinson, Lifetime  
 George H, Robinson, Lifetime  
 Kenneth, Roblee, Active  
 Shirley, Rohrer, Active  
 Frank, Romano, Active  
 Donald, Roush, Lifetime  
 Robert, Rowe, Student  
 Bobby, Rowe, Lifetime

Jane, Roy, Active  
Albert E., Russell, Active  
Gullo, Safawo, Active  
Kristina, Schneider, Student  
Lacoya Tyne, Seltzer, Student  
PC, Sharma, Lifetime  
David L, Shealy, Lifetime  
Richard C, Sheridan, emeritus  
RL, Shoemaker, emeritus  
Michelle, Sidler, Active  
Shiva P, Singh, Lifetime  
Kenneth R, Sloan, Lifetime  
Akeem, Smith, Student  
Lynessa V., Smith, Student  
Anita, Smith, Active  
Micky, Smith, Lifetime  
Bruce F, Smith, Active  
Angela M., Spano, Student  
Sheldon, Spencer, Student  
Clyde T, Stanton, Active  
Ariel D., Stark, Student  
James L., Stewart, Student  
Samuel J, Strada, Active  
Chrystal, Sullivan, Student  
Kenneth, Sundberg, Active  
Arjun, Tan, Active  
Robert W, Thacker, Active  
Shamira, Theodore, Student  
Robert E, Thomas, Active  
D Brian, Thompson, Active  
Jerry N, Thompson, Active  
Sue, Thomson, Active  
Trygve, Tollefsbol, Active  
Perry, Tompkins, Lifetime  
Diane, Tucker, Active  
Charmaine, Tutson, Student  
Katherine, Vandeven, Student  
SL, Varghese, Active  
Nagiarajan, Vasumathi, Active  
John B, Vincent, Active  
Kris, Walker, Student  
JH, Walker, Lifetime

Natalie, Warren, Student  
Stephen A, Watts, Lifetime  
Clifford, Webb, Student  
BC, Weber, Lifetime  
Laura, Weinkauf, Active  
Glynn P, Wheeler, emeritus  
Thane, Wibbels, Active  
WH, Wilborn, Lifetime  
James C, Wilkes, Lifetime  
Brandon, Williams, Student  
Shammah O.N., Williams, Student  
Robert J, Williams, Lifetime  
Edward L, Wills, Active  
Katie, Wilson, Student  
Herman, Windham, Active  
Patrick L., Witmer, Student  
Michael, Woods, Active  
Emily, Wright, Student  
Douglas A., Wymer, Active  
Lin, Yang, Student









# Alabama Academy of Science Journal

## Scope of the Journal:

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- Manuscript layout should follow the specific guidelines of the journal.
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- At least one author must be a member of the *Alabama Academy of Science* (except for Special Papers).
- The author(s) should provide the names and addresses of at least two potential reviewers.
- Assemble the manuscript in the following order: Title Page, Abstract Page, Text, Brief acknowledgments (if needed), Literature Cited, Figure Legends, Tables, Figures.

## What and Where to Submit:

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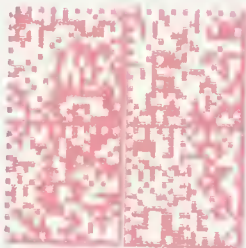
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The Journal of the Alabama  
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Received on: 07-05-07



100232744

